OCEAN DISCHARGE CRITERIA EVALUATION
FOR THE NPDES GENERAL PERMIT
FOR THE GULF OF MEXICO OCS
DRAFT

April 4, 1991

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1. INTRODUCTION

1.1 BACKGROUND

The Clean Water Act Section 402 authorizes the Environmental Protection Agency (EPA) to issue National Discharge Elimination System (NPDES) permits to regulate discharges to waters of the U.S. EPA Region 6 is issuing an NPDES general permit for waters on the Outer Continental Shelf (OCS) of the Gulf of Mexico for effluent discharges associated with oil and gas exploration, development and production activities. Sections 402 and 403 of the Clean Water Act require that NPDES permits for discharges to the territorial seas (baseline to 3 miles), the contiguous zone, and the ocean be issued in compliance with EPA's regulations for preventing unreasonable degradation of the receiving waters.

Prior to permit issuance, discharges must be evaluated against EPA's published criteria for determination of unreasonable degradation. Unreasonable degradation is defined in the NPDES regulations (40 CFR 125.121[e]) as

1. Significant adverse changes in ecosystem diversity, productivity, and stability of the biological community within the area of discharge and surrounding biological communities

2. Threat to human health through direct exposure to pollutants or through consumption of exposed aquatic organisms

3. Loss of aesthetic, recreational, scientific or economic values, which is unreasonable in relation to the benefit derived from the discharge.

The ten factors that are specified at 40 CFR 125.122 for determining unreasonable degradation are the following:

1. The quantities, composition, and potential for bioaccumulation or persistence of the pollutants to be discharged

2. The potential transport of such pollutants by biological, physical or chemical processes

3. The composition and vulnerability of the biological communities which may be exposed to such pollutants, including the presence of unique species or communities of species, the presence of species identified as endangered or threatened pursuant to the Endangered Species Act, or the presence of those species critical to the structure or function of the ecosystem, such as those important for the food chain

4. The importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage areas, migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism

5. The existence of special aquatic sites including, but not limited to, marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas, and coral reefs

6. The potential impacts on human health through direct and indirect pathways

7. Existing or potential recreational and commercial fishing, including finfishing and shellfishing

8. Any applicable requirements of an approved Coastal Zone Management plan

9. Such other factors relating to the effects of the discharge as may be appropriate

10. Marine water quality criteria developed pursuant to Section 304(a)(1).

In the event either that an assessment of these 10 factors determines that unreasonable degradation may occur even with proposed technology- and water quality-based permit conditions in place, or that a determination cannot be made due to lack of data, Section 403(c) authorizes the Agency to impose more stringent permit conditions and/or monitoring.

1.2 SCOPE

This Ocean Discharge Criteria Evaluation (ODCE) will address the ten factors for determining unreasonable degradation as outlined above and at 40 CFR 125.122. It will also assess whether the information exists to make a "no unreasonable degradation" determination including any permit conditions that may be necessary to make that determination.

Section 2 of this document describes the physical and chemical oceanography relevant to the coverage area, and addresses Factor 2 of the 10 factors listed above. The quantities and composition of materials that are potentially discharged from covered facilities (Factor 1) are described in Section 3 of this document. The fourth section of this ODCE describes the transport and persistence characteristics of the discharges (Factor 2). Section 5 summarizes the toxicity and bioaccumulation characteristics of the discharged materials (Factors 1 and 6). The biological communities, endangered species, and the importance of the receiving waters to those species (Factors 3 and 4) are presented in Section 6 of this document. Commercial and recreational fisheries are discussed in Section 7 (Factor 7). Because the OCS general permit covers an area beyond State waters, the permit is not subject to state Coastal Zone Management Plan (CZMP) requirements. However, this document reviews the approved CZMP of Louisiana (Texas does not have an approved plan) including special aquatic sites, in Section 8 and discusses the consistency of the proposed

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permit with that plan (Factors 5, 7, and 8). Section 9 compares Federal marine water quality and human health criteria and Texas and Louisiana state water quality standards (Factor 10) to water column pollutant concentrations to assess potential impacts of the discharge, both to human health (Factor 6) and to biological communities (Factors 3 and 4).

This ODCE, in Section 10 offers the Agency's determination of consistency with the appropriate regulations and standards and any permit conditions necessary to achieve that consistency.

2. PHYSICAL AND CHEMICAL OCEANOGRAPHY

2.1 PHYSICAL OCEANOGRAPHY

2.1.1 Circulation

Regional Overview

Circulation patterns in the Gulf of Mexico are characterized by two interrelated systems, the offshore of open Gulf, and the shelf or inshore Gulf. Both systems involve the dynamic interaction of a variety of factors. The Loop Current is the major influence on circulation in the eastern Gulf of Mexico, and the Mississippi River is the major influence in the central Gulf. The absence of these major influences in the western Gulf makes this area unique; however, influential eddies and gyres from the Loop Current often move from the eastern Gulf, through the central Gulf, and eventually dissipate in the western Gulf.

The Loop Current forms as the Yucatan Current enters the Gulf through the Yucatan Straits and travels through the eastern and central Gulf before exiting the Gulf via the Straits of Florida and merging with other water masses to become the Gulf Stream. The location of the Loop Current varies, although the average positions between months do not differ significantly. The Loop Current is located primarily in the central Gulf and eastern Gulf, but protrudes into the northern section of the eastern and central Gulf through an annual cycle of growth and decay (Leipper, 1970; Maul, 1977).

Other influences on circulation in the open Gulf are the semipermanent gyre in the western Gulf (believed to be fed both by Loop Current eddies that drift into the region and by wind stress), winds, waves, freshwater input, and the density of the water column. In the shelf or inshore Gulf region, localized circulation patterns are affected by topography, tides, local winds, freshwater input, and some influence from the open Gulf's circulation features.

Wind patterns in the Gulf are primarily anticyclonic (clockwise around high pressure areas). During the winter, mean speeds range from 8 to 18 knots. The northern Gulf is strongly influenced by polar continental air masses ("northers") moving southward over Texas and Louisiana. When these northerly air masses interact with the moist, warm air of the Gulf, they stall, form low pressure centers, and move

eastward. The frequency and severity of these "northers" determine winter water temperatures along the northern coast. Prevailing winds for the months of January and July off Texas and Louisiana are presented in Figures 2-1 and 2-2.

The tides in the Gulf of Mexico are less developed and have smaller ranges than those in other coastal areas of the United States. The ranges are usually 0.3 to 1.2 meters depending on the location and time of year. The Gulf has three types of tides, which vary throughout the area; diurnal, semidiurnal, and mixed (both diurnal and semidiurnal; Figure 2-3). Wind and barometric conditions will influence the daily fluctuations in sea level. Onshore winds and low barometric readings or offshore winds and high barometric readings will cause the daily waters to be higher or lower than predicted. In shelf areas, meteorological conditions occasionally mask local tidal-induced circulation. Although extreme weather conditions are infrequent in the Gulf, tropical storms in summer and early fall may affect the area with high winds (18+ meters per second), waves (7+ meters), and storm surge (3 to 7.5 meters) or winter storm systems may cause moderately high winds, waves, and storm conditions that mask local tides.

Central Gulf of Mexico and Louisiana Circulation

The strongest influences on circulation patterns in the central Gulf of Mexico area are runoff from the Mississippi River system and Loop Current intrusions. Since the Louisiana shelf and slope area lacks any major regional structures, cold water intrusions resulting from both river runoff and wind-driven effects on shelf water may cause strong southerly movement of water well beyond the shelf break.

Although the area west of the Mississippi River is influenced by occasional Loop Current intrusions (Vukovich et al., 1978; Leipper, 1970), the surface currents in this region are attributed primarily to tides and winds on the shelf and wind stress in offshore areas. Occasionally, an anticyclonic eddy will pass through in the mid-latitudes (around 27°N), affecting the offshore areas. Surface currents with moderate velocities generally have a westerly movement in this region during winter and spring months (Figure 2-4) or an easterly movement during summer months (Figure 2-5), unless modified by Loop Current eddies passing through.

Western Gulf of Mexico and Texas Circulation

The physical oceanography in the western Gulf of Mexico differs from the rest of the Gulf due to the greatly decreased influence of the Loop Current. As stated above, Loop Current eddies traveling westward through the Gulf eventually dissipate in the western Gulf area.

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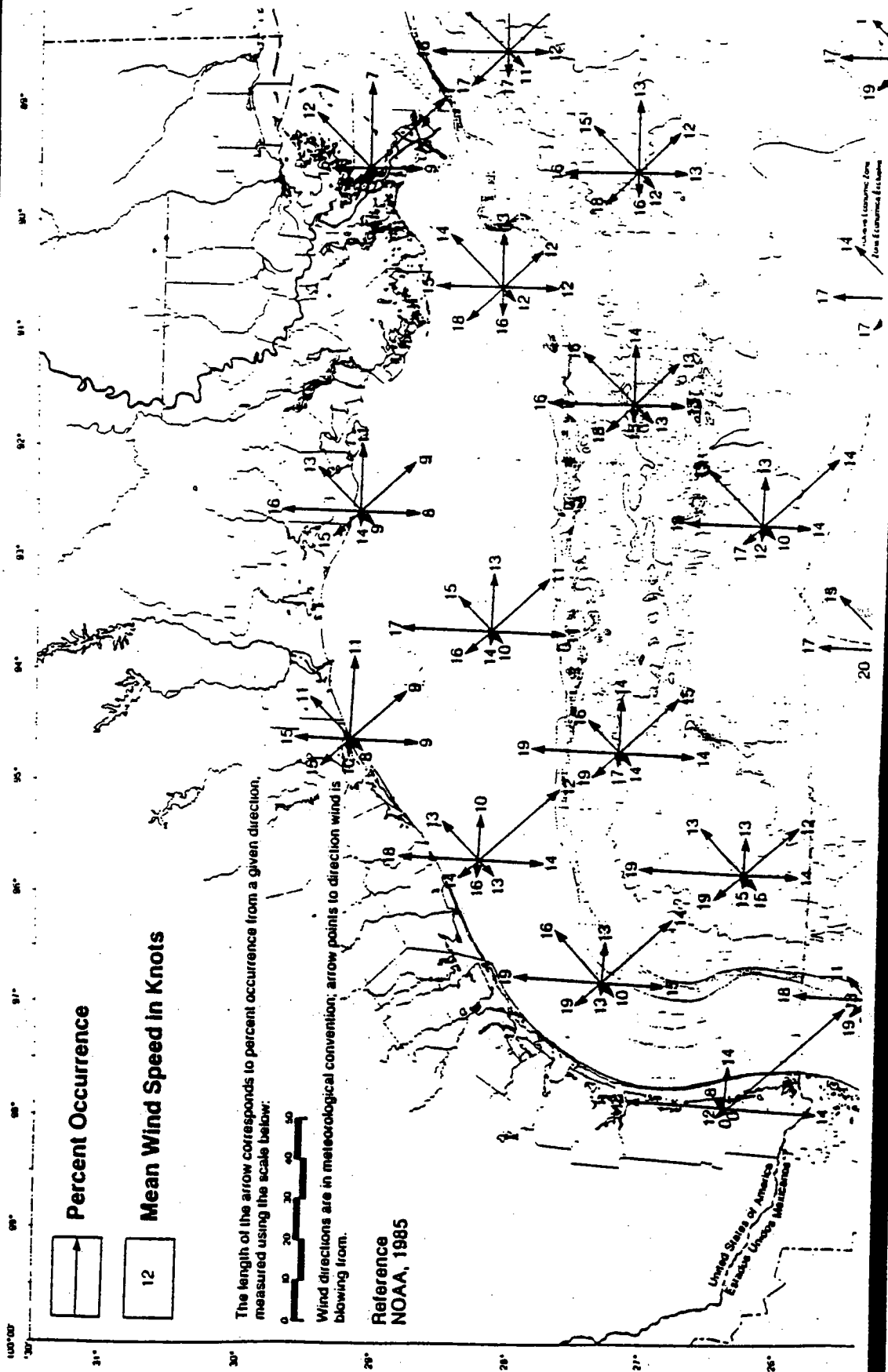
Figure 2-1. Prevailing Winds: January
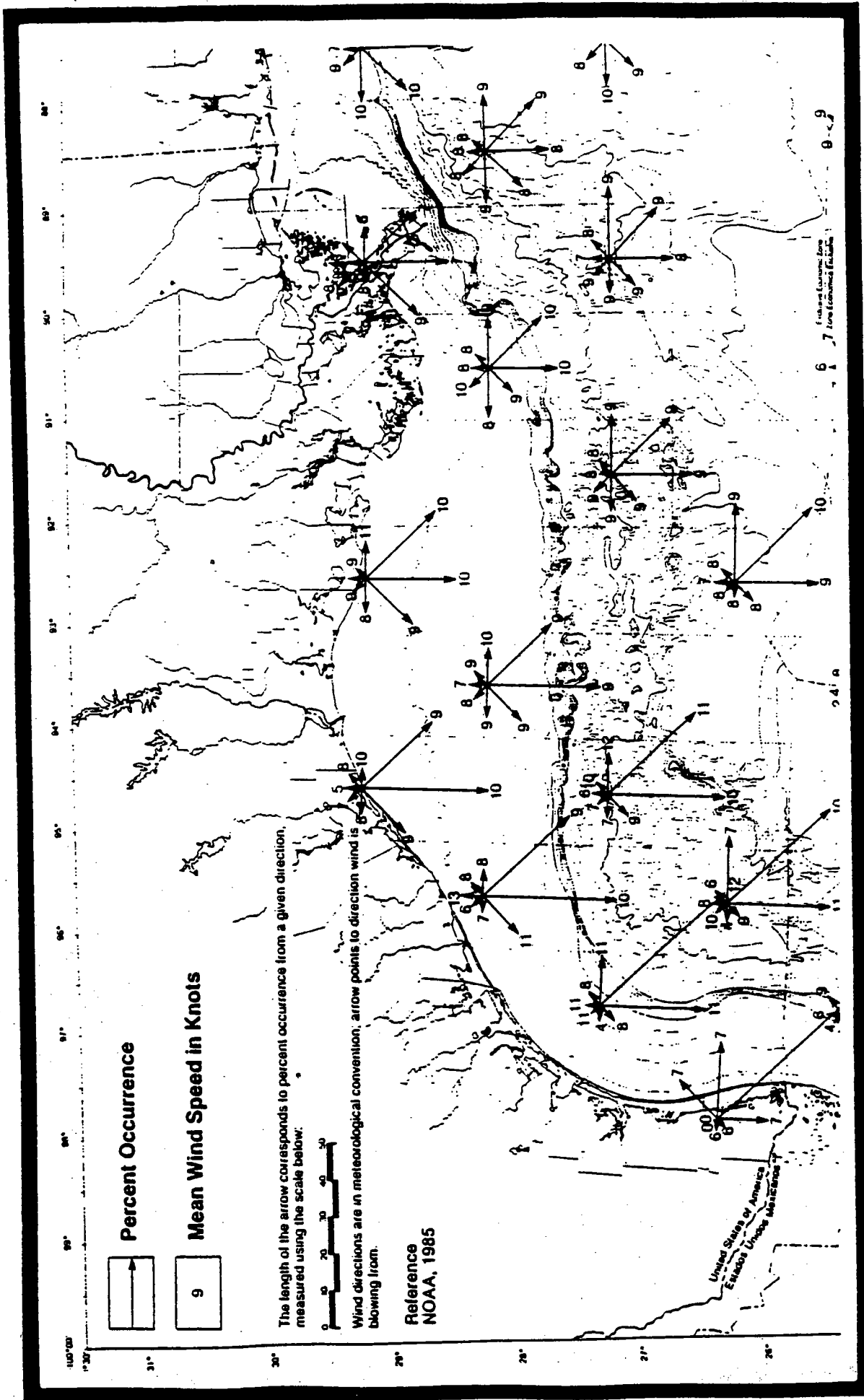
Figure 2-2. Prevailing Winds: July

Percent Occurrence

Mean Wind Speed in Knots

9

The length of the arrow corresponds to percent occurrence from a given direction, measured using the scale below.

Wind directions are in meteorological convention; arrow points to direction wind is blowing from.

Reference
NOAA, 1985

United States of America
Estados Unidos Mexicanos

EPA_COOK_INKPR_020319
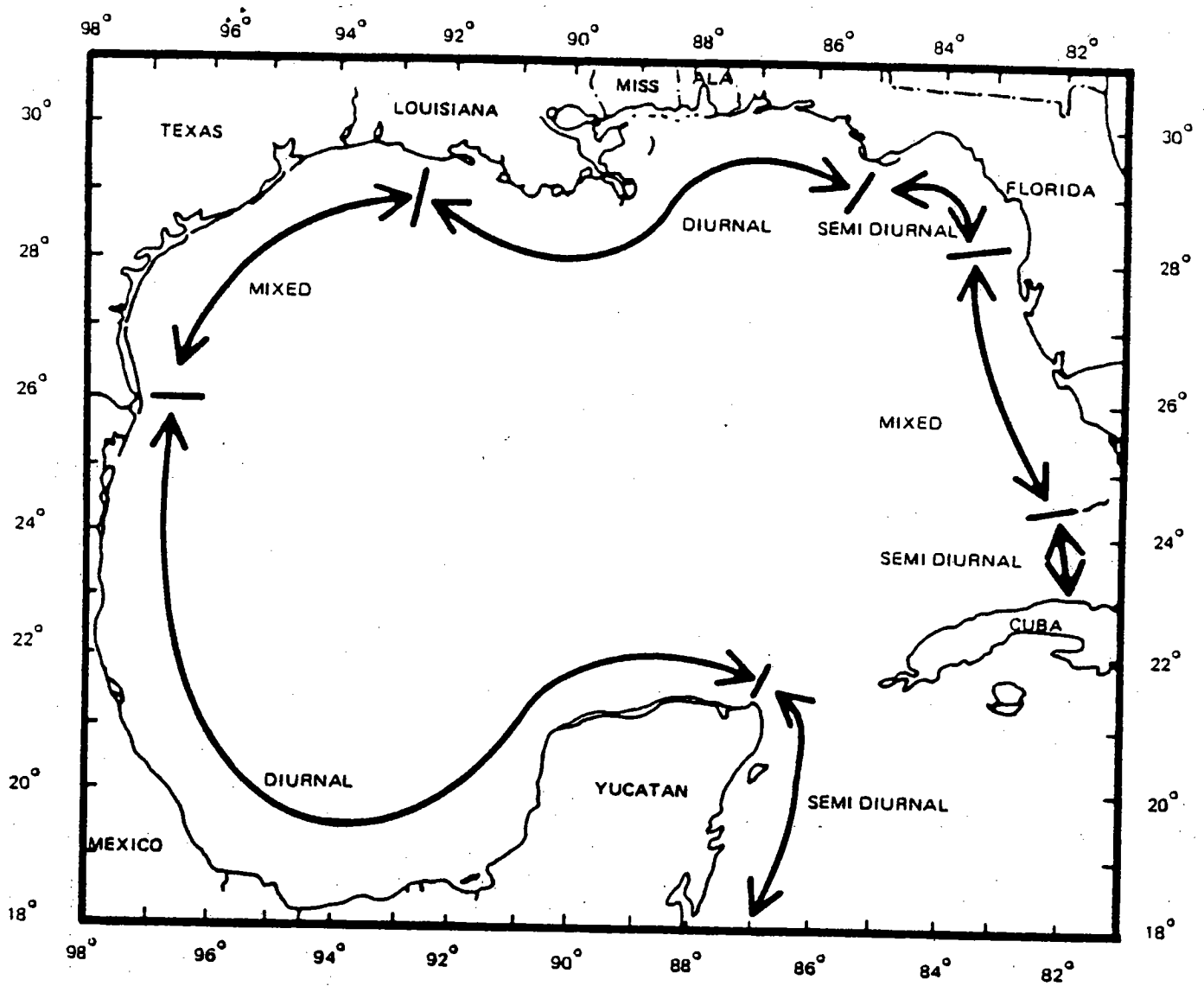
Figure 2-3. Gulf of Mexico Tidal Regimes (Eleuterius, 1979)
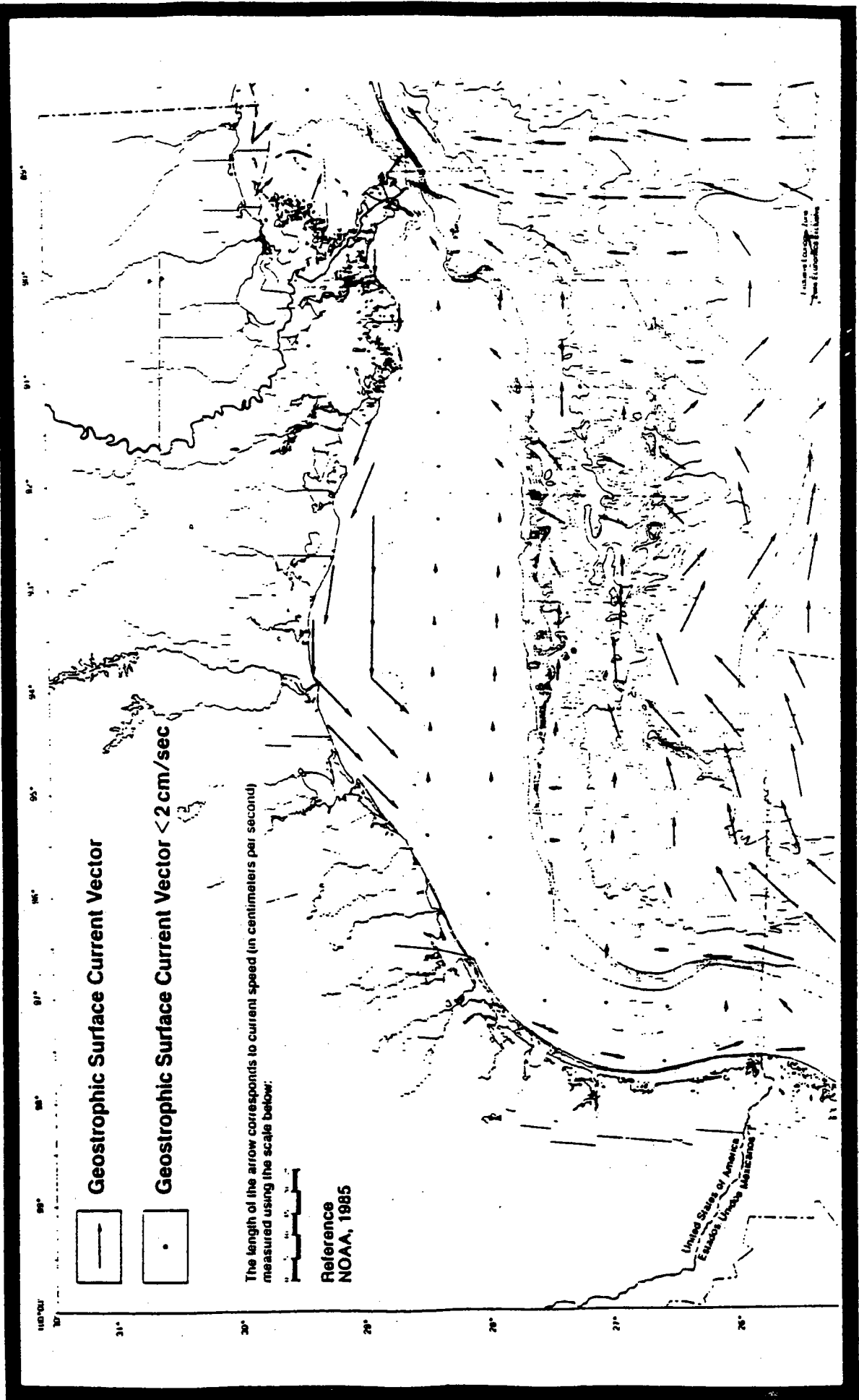
Figure 2-4. Geostrophic Surface Currents: January

Geostrophic Surface Current Vector

Geostrophic Surface Current Vector <2 cm/sec

The length of the arrow corresponds to current speed (in centimeters per second) measured using the scale below:

Reference
NOAA, 1985
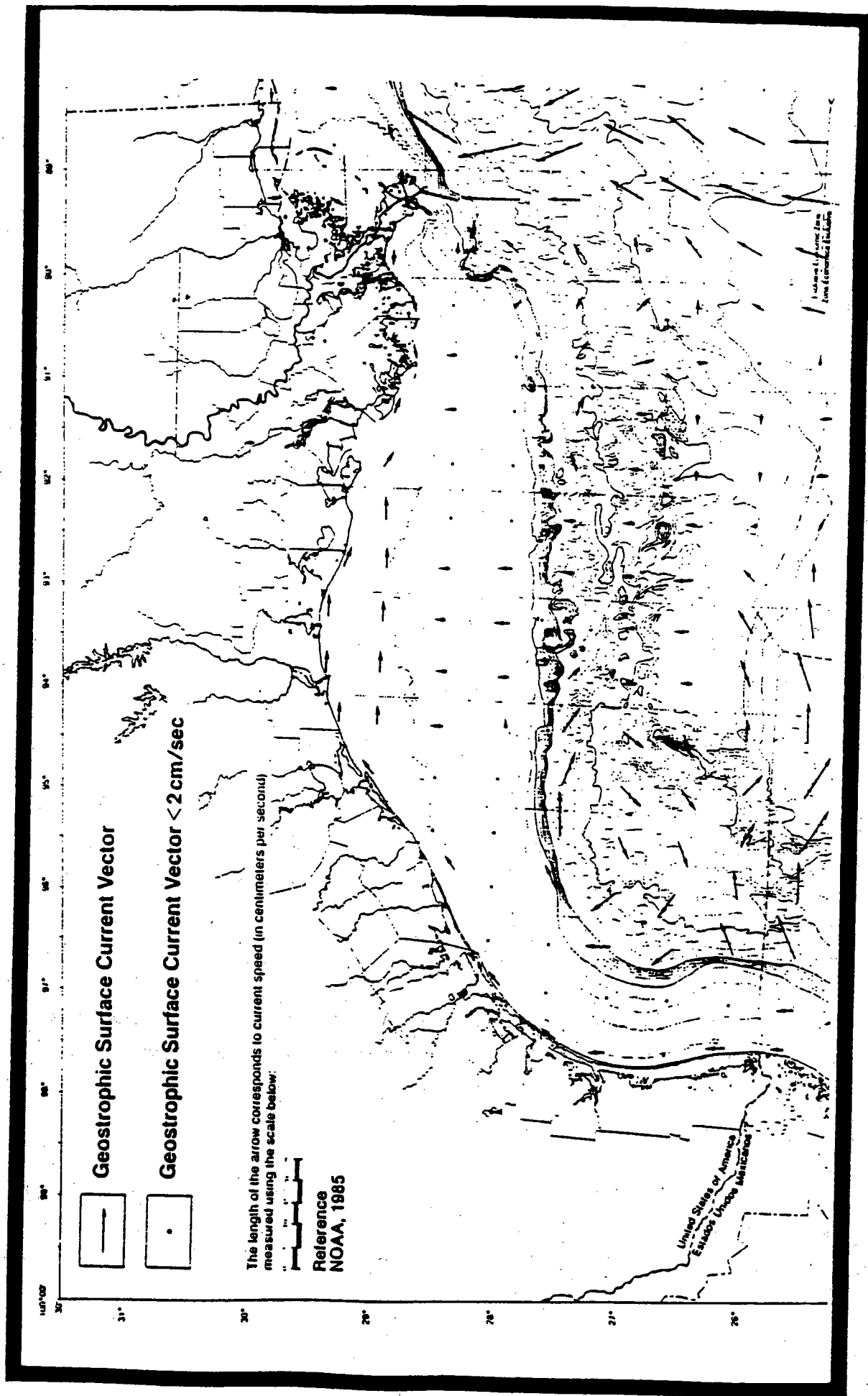
Figure 2-5. Geostrophic Surface Currents: July

Another major feature that has a pronounced effect on circulation in the area is the semipermanent anticyclonic gyre formed by both wind stress and Loop Current eddies. The gyre exists between 22° and 25°N latitude and has a north-south diameter of about 220 kilometers and an east-west diameter of about 400 kilometers.

The general flow pattern for the Texas offshore area follows the coastline and is southerly during the winter, turning to the east at about 25°N latitude (see Figure 2-4). In summer, the flow is northerly to about 94°W longitude off Louisiana where it converges with an opposing flow to the north and northeast.

The average current velocities in the northwest Gulf of Mexico range fro 10 to 30 centimeters per second with a maximun velocity range from 53 to 180 centimeters per second (Danek and Tomlinson, 1980). Current velocities correspond to wind changes, with approximately a 12-hour lag time for full response of the currents to wind changes. Table 2-1 depicts a comparison of observed winds and currents for several depths at the Buccaneer Oil Field in the northwest area of the Gulf.

2.1.2 Temperature, Salinity, and Dissolved Oxygen

Temperature

Sea surface temperatures in the Gulf range from nearly isothermal (29-30°C) in August to a sharp horizontal gradient in January, ranging from 25°C in the Loop core to values of 14-15°C along the shallow northern coastal estuaries. August temperatures at 150 m show a warm Loop Current and an anticyclonic feature in the Western Gulf (both about 18-19°C) grading into surrounding waters of 15-16°C along the slope. The range of surface sea temperatures in the western Gulf tends to be lower than the range in the eastern Gulf, reflecting the difference in the contribution of the Loop Current. The entire pattern is maintained during winter, but warmer by about 1°C.

A 7°C sea surface temperature gradient occurs in the winter from north to south across the Gulf, mainly over the northern shelf region (Figure 2-6). During the summer, sea surface temperatures span a much narrower range (Figure 2-7). The lowest values may be as low as 10°C in the Louisiana-Mississippi shelf region depending on snow melt from the upper Mississippi Valley.

The depth of the thermocline, defined as the depth at which the temperature gradient is a maximum, is important because it demarcates the bottom of the mixed layer and acts as a barrier to the vertical transfer of materials and momentum. During January, the thermocline depth is about 91-107 m in the Central and

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Table 2-1. Summary of Wind and Currents for the Gulf of Mexico Buccaneer Oil Field July 26-August 30, 1978, and February 14-March 20, 1979

	July-August 1978	February-March 1979
Wind		
Direction (from °T)	180 (S)	045 (NE)
Mean speed (m/s)	3.9	7.1
Maximum speed (m/s)	16.1	15.2
Currents (4.5 m)		
Mean speed (cm/s)	17.8	18.6
Maximum speed (cm/s)	62.0	58.0
Residual speed (cm/s)	3.0	13.5
Residual direction (towards °T)	185 (S)	250 (WSW)
Currents (10.5 m)		
Mean speed (cm/s)	12.9	15.2
Maximum speed (cm/s)	57.0	60.0
Residual speed (cm/s)	4.3	9.4
Residual direction (towards °T)	23 (SW)	250 (WSW)
Currents (18.0 m)		
Mean speed (cm/s)	7.3	11.2
Maximum speed (cm/s)	46.0	42.0
Residual speed (cm/s)	3.4	4.4
Residual direction (towards °T)	250 (WSW)	260 (W)

Source: Danek and Tomlinson, 1980.

Figure 2-6. Surface Temperatures: January
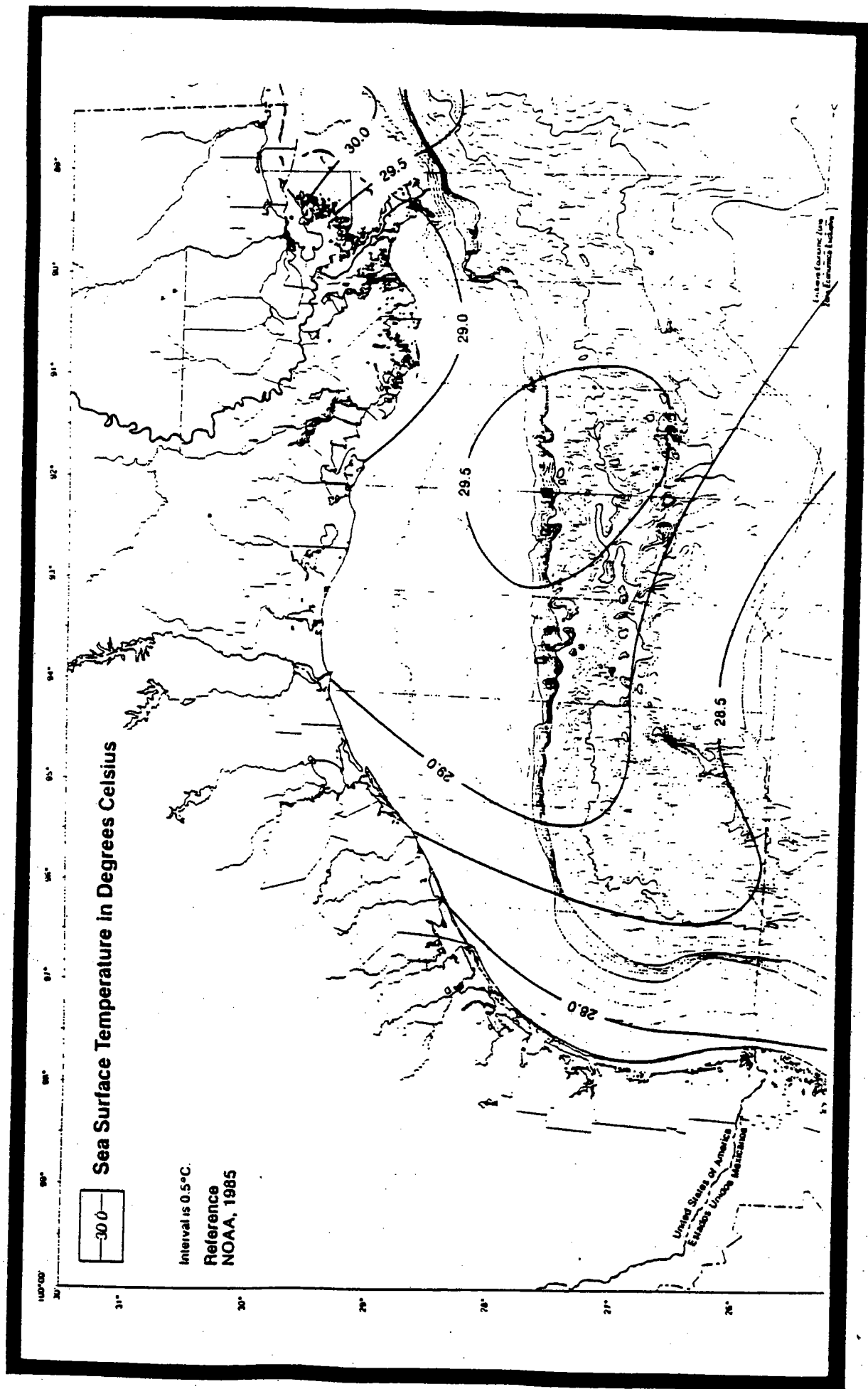
Figure 2-7. Surface Temperatures: July

Western Gulf. In May, the thermocline depth is about 46 m throughout the entire Gulf (Robinson, 1973 in MMS, 1990).

At 1,000 m, the temperature remains close to 5°C year-round (MMS, 1990). In winter, nearshore bottom temperatures on the northern Gulf of Mexico are 3-10°C cooler than those temperatures offshore (Figure 2-8). A permanent seasonal thermocline occurs in deeper offshelf waters throughout the Gulf. The intersection of this offshelf thermocline structure with the isothermal water structure on the shelf results in a northern temperature of about 20°C off Texas. In summer, warming surface waters help raise bottom temperatures in all shelf areas, producing a monotonically decreasing distribution of bottom temperatures from about 28°C at the coast to about 18°-20°C at the shelf break (Figure 2-9).

Salinity

Surface salinities along the northern Gulf display seasonal variations because of the seasonality of the freshwater input. During months of low freshwater input, deep Gulf water penetrates into the shelf and salinities near the coastline range between 29-32‰. High freshwater input conditions (spring-summer months) are characterized by strong horizontal gradients and inner shelf salinity values of less than 20‰ (MMS, 1990).

Dissolved Oxygen

Dissolved oxygen values in the mixed layer average 4.6 mg/l, with some seasonal variation, particularly during the summer months when a slight lowering can be observed. Oxygen values generally decrease to about 3.5 mg/l with depth through the mixed layer. In some offshore areas in the northern Gulf of Mexico, hypoxic (<2.0 mg/l) and occasionally anoxic (<0.1 mg/l) bottom water conditions are widespread and seasonally regular (Rabalais, 1986). These conditions have been documented since 1972 and have been observed mostly from June to September on the inner continental shelf at 5 to 50 meters depth (Renauld, 1985; Rabalais et al, 1985). The phenomenon is better known in the Mississippi River delta bight west of the river's discharge, and on the inner shelf west of the Atchafalaya River off Cameron, Louisiana (Rabalais, 1986).

2.2 CHEMICAL OCEANOGRAPHY

The Gulf of Mexico is a semienclosed system with oceanic input through the Yucatan Channel and principal outflow through the Straits of Florida. Runoff from approximately two-thirds of the area of the

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Bottom Temperature in Degrees Celsius

Bottom temperatures are shown only to a depth of 200 meters.

Reference
NOAA, 1985

Figure 2-8. Bottom Temperatures: Winter
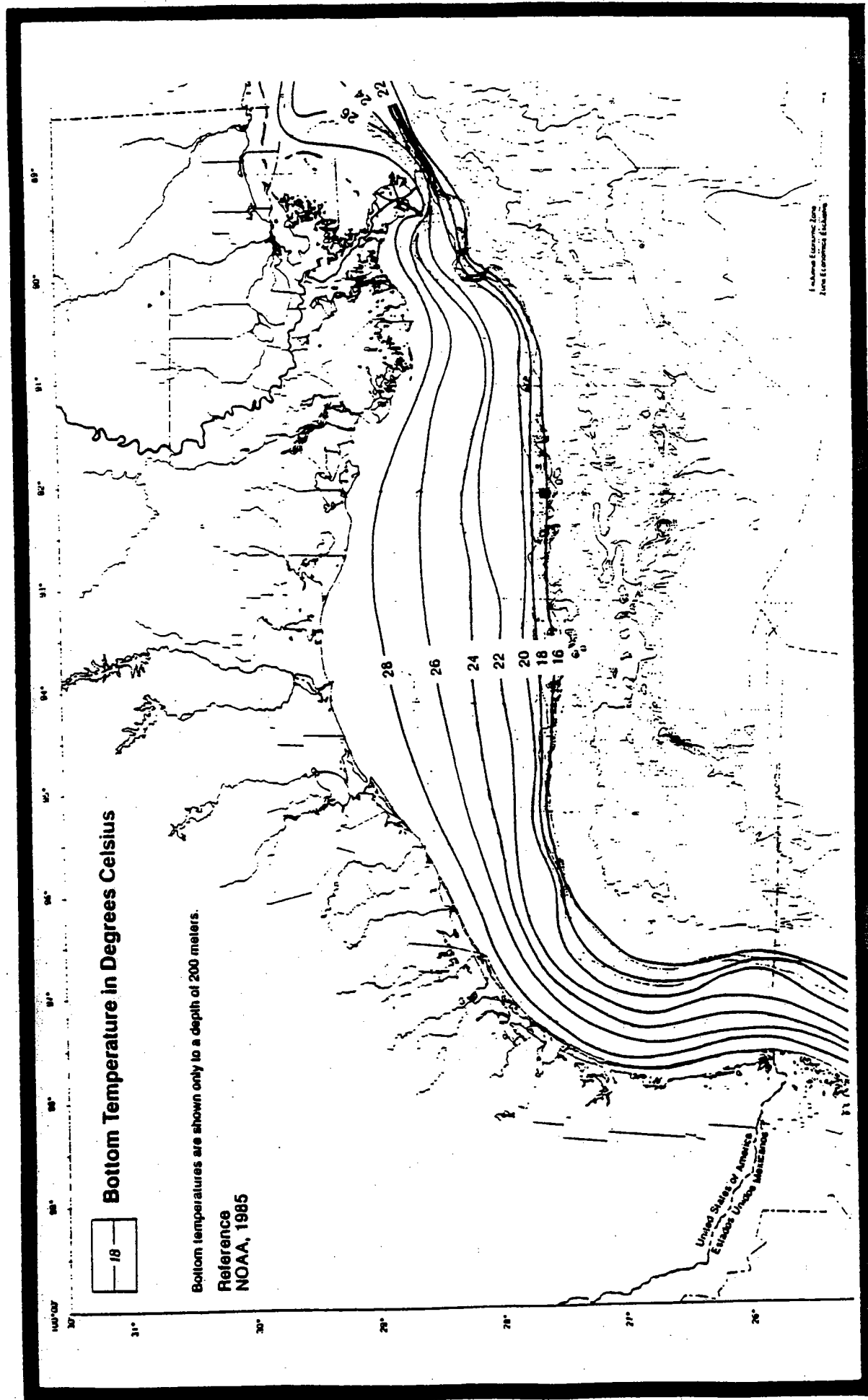
Figure 2-9. Bottom Temperatures: Summer

U.S. and more than one-half of the area of Mexico empties into the Gulf. This large amount of runoff with its nonoceanic composition is mixed into the surface water of the Western Gulf and makes the chemistry of parts of this system quite different from the open ocean. Figure 2-10 shows the freshwater contribution of significant rivers in Texas and Louisiana.

Micronutrients

The principal micronutrients about which generalizations can be drawn are phosphate, nitrate, and silicate. Phytoplankton consume phosphorus and nitrogen in an approximate ratio of 1:16 for growth. The following nutient levels and distribution values were obtained from MMS (1990). Phosphates range from 0-0.25 ppm, averaging 0.021 ppm in the mixed layer. Shelf values do not vary significantly from open Gulf values. Silicates range predominantly from 0.048 to 1.9 ppm and open Gulf values tend to be lower than shelf values.

In the western Gulf, although the overall nutrient values are somewhat lower over the outer shelf and slope than for inshore waters, an intrusion of nutrient-rich, oxygen-poor water from apparent depths of 200-300 m is indicated in many cases, with effects seen up to 70 m in depth. An area of major upwelling has been indicated along the shelf break.

In the central Gulf, less is known about the chemical oceanography. Waters over the outer shelf and slope are affected by the Mississippi and upwelling of cooler, nutrient-rich waters, although the pattern is not fully understood. Detached, anticyclonic eddies may also be important in determining a pattern.
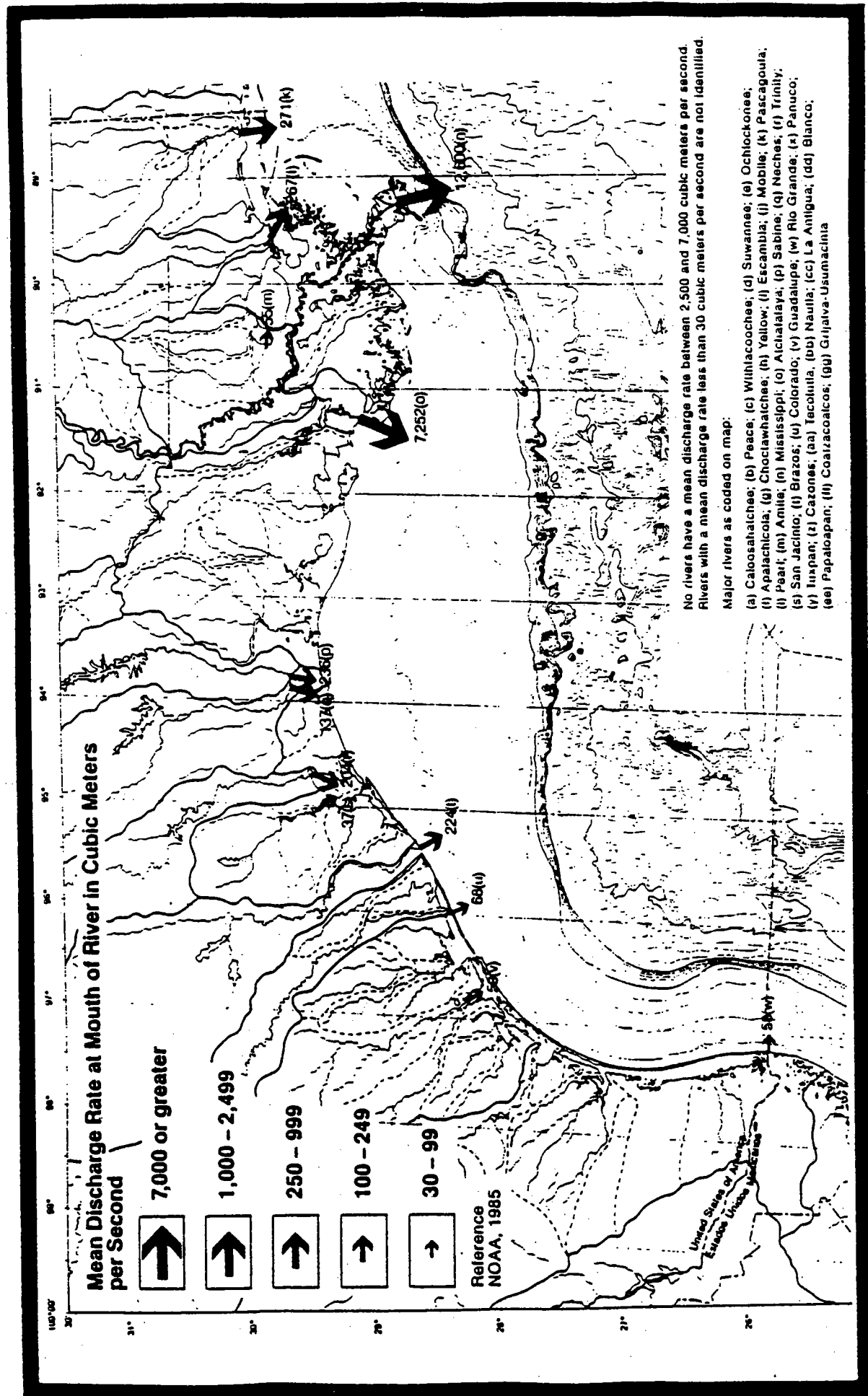
Figure 2-10. Rivers

3. DISCHARGED MATERIAL

3.1 DISCHARGES COVERED IN OCS GENERAL PERMIT

The following discharges have been characterized by their sources and uses during drilling and production operations and by their physical and chemical compositions:

Drilling Fluids
Drill Cuttings
Deck Drainage
Produced Water
Produced Sand
Sanitary Wastes
Domestic Wastes
Completion Fluids
Cement
Workover Fluids
Water Flooding Discharges
Blowout Preventer Control Fluids
Desalination Unit Discharges
Fire Control System Test Water
Non-Contact Cooling Water
Ballast and Storage Displacement Water
Bilge Water

3.2 DRILLING FLUIDS

Drilling fluids (also known as drilling muds or muds) are suspensions of solids and dissolved materials in a water or oil base that are used in rotary drilling operations. The rotary drill bit is rotated by a hollow drill stem made of pipe, through which the drilling fluid is circulated. Drilling fluids are formulated for each well to meet specific physical and chemical requirements. Geographic location, well depth, rock type, geologic formation, and other conditions affect the mud composition required. The number and nature of mud components varies by well, and several to many products may be used at any time to create the necessary properties. The basic functions of a drilling fluid include

- Transport drill cuttings to the surface
- Suspend drill cuttings in the annulus when circulation is stopped
- Control subsurface pressure
- Cool and lubricate the bit and drill string

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- Support the walls of the wellbore
- Help suspend the weight of the drill string and casing
- Deliver hydraulic energy upon the formation beneath the bit, and
- Provide a suitable medium for running wireline logs (U.S. EPA, 1985).

Five basic components account for approximately 90 percent by weight of the materials that compose drilling muds:

- Barite
- Clay
- Lignosulfonate
- Lignite
- Caustic soda.

Barite

In water-based muds, barite is composed of 80-90 percent barium sulfate. It is used to increase the density of the drilling fluid to control formation pressure. The concentration of barite can be as high as 700 lb/bbl. Quartz, chert, silicates, other minerals, and trace levels of metals can also be present in barite.

Clay

The most common clay used is bentonite, which is composed mainly of (60-80%) sodium montmorillonite clay. It can also contain silica, shale, calcite, mica, and feldspar. Bentonite is used to maintain the rheologic properties of the fluid and prevent loss of fluid by providing filtration control in permeable zones. The concentration of bentonite in mud systems is usually 5 to 35 lb/bbl.

Lignosulfonate

Lignosulfonate is used to control viscosity in drilling muds by acting as a thinning agent or deflocculant for clay particles. Concentrations range from 1 to 15 lb/bbl. It is made from the sulfite pulping of wood chips to produce paper and cellulose. Chrome lignosulfonate is made by treating lignosulfonate with sulfuric acid and sodium dichromate. The sodium dichromate oxidizes the lignosulfonate and cross linking occurs. Hexavalent chromium supplied by the chromate is reduced during reaction to the trivalent state and complexes with the lignosulfonate. At high down-hole temperatures, the chrome binds onto the edges of clay particles and reduces the formation of colloids.

Lignite

Lignite is a soft coal used in drilling muds as a deflocculant for clay and to control the filtration rate. Concentrations vary from 1 to 15 lb/bbl. Most lignite (leonardite) is mined in North Dakota and consists mostly of humic acid.

Caustic Soda

Sodium hydroxide is used to maintain the pH of drilling muds between 9 and 12. A pH of 9.5 provides for maximum deflocculation and keeps the lignite in solution. A more basic pH lowers the corrosion rate and provides protection against hydrogen sulfide contamination by limiting microbial growth.

Drilling fluids can be water based or oil based. In water-based muds, water is the suspending medium for solids and is the continuous phase, whether or not oil is present. Water-based drilling fluids are composed of approximately 50 to 90 percent water by volume, with additives comprising the rest. Water-based muds may contain diesel oil in greater than trace amounts. The diesel, up to 4 percent, is added to reduce torque and drag. In a stuck pipe situation, a "pill" (diesel oil or oil-based drill fluid) is pumped down the drill string and "spotted" in the annulus area. The pill may or may not be separated out of the bulk fluid system. If the pill is removed, a small amount of diesel remains with the mud system.

Oil-based drilling fluids are those with oil, typically diesel, as the continuous phase and water as the dispersed phase. These fluids contain blown asphalt and usually one to five percent water emulsified into the system with caustic soda or quicklime and organic acid. Silicate, salt, and phosphate may also be present. Oil-based muds are generally more costly and are more toxic to marine organisms than water-based muds. They are normally used in more difficult drilling conditions. The advantages of oil-based muds include excellent thermal stability when drilling deep, high-temperature wells; better lubricating characteristics for drilling deviated wells; and the ability to drill thick, water-sensitive shales with fewer stuck pipe or hole washout problems. The primary disadvantage of diesel oil-based systems is their adverse environmental impact. Mineral oil-based mud systems have been proven to be a less toxic alternative.

Drilling fluids can be classified into eight generic types based on their compositions, which are presented in Table 3-1. These mud types are:

1. Potassium/polymer fluids are inhibitive fluids, as they do not change the formation after it is cut by the drill bit. They are used in soft formations such as shale.

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Table 3-1. EPA Generic Drilling Mud Types[a]

Components	Pounds per Barrel
1. Seawater/Potassium/Polymer Mud	
KCl	5-50
Starch	2-12
Cellulose Polymer	0.25-5
XC Polymer	0.25-2
Drilled Solids	20-100
Caustic	0.5-3
Barite	0-450
Seawater	As needed
2. Seawater/Lignosulfonate Mud	
Attapulgite or Bentonite	10-50
Lignosulfonate	2-15
Lignite	1-10
Caustic	1-5
Barite	25-450
Drilled Solids	20-100
Soda Ash/Sodium Bicarbonate	0-2
Cellulose Polymer	0.25-5
Seawater	As needed
3. Lime Mud	
Lime	2-20
Bentonite	10-50
Lignosulfonate	2-15
Lignite	0-10
Barite	25-180
Caustic	1-5
Drilled Solids	20-100
Soda Ash/Sodium Bicarbonate	0-2
Freshwater	As needed
4. Nondispersed Mud	
Bentonite	5-15
Acrylic Polymer	0.5-2
Barite	25-180
Drilled Solids	20-70
Freshwater	As needed

(continued)

[a] Source: Cole and Mitchell, 1984

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Table 3-1. EPA Generic Drilling Mud Types (continued)

Components	Pounds per Barrel
5. Spud Mud (slugged intermittently with seawater)	
Attapulgite or Bentonite	10-50
Lime	0.5-1
Soda Ash/Sodium Bicarbonate	0-2
Caustic	0-2
Barite	0-50
Seawater	As needed
6. Seawater/Freshwater Gel Mud	
Attapulgite or Bentonite Clay	10-50
Caustic	0.5-3
Cellulose Polymer	0-2
Drilled Solids	20-100
Barite	0-50
Soda Ash/Sodium Bicarbonate	0-2
Lime	0-2
Seawater/Freshwater	As needed
7. Lightly Treated Lignosulfonate Freshwater/Seawater Mud	
Bentonite	10-50
Barite	0-180
Caustic	1-3
Lignosulfonate	2-6
Lignite	0-4
Cellulose Polymer	0-2
Drilled Solids	20-100
Soda Ash/Sodium Bicarbonate	0-2
Lime	0-2
Seawater to Freshwater Ratio	1:1 approx.
8. Lignosulfonate Freshwater Mud	
Bentonite	10-50
Barite	0-450
Caustic	2-5
Lignosulfonate	4-15
Lignite	2-10
Drilled Solids	20-100
Cellulose Polymer	0-2
Soda Ash/Sodium Bicarbonate	0-2
Lime	0-2
Freshwater	As needed

2. Seawater/lignosulfonate fluids are also inhibitive. This type of mud is used to maintain viscosity by binding lignosulfonate cations onto the broken edges of clay particles. It is also used to control fluid loss and to maintain the borehole stability. Under more complicated conditions, such as higher temperatures, this type of mud can be easily altered.

3. Lime (or calcium) fluids are inhibitive fluids. The viscosity of the mud is reduced as calcium binds the clay platelets together to release water. This type of mud system can maintain more solids. Lime fluids are used in hydratable, sloughing shale formations.

4. Nondispersed fluids are used to maintain viscosity, to prevent fluid loss, and to provide improved penetration, which may be impeded by clay particles in dispersed fluids.

5. Spud fluids are noninhibitive muds that are used in approximately the first 300 meters of drilling. This is the most simple mixture of mud and contains mostly seawater and a few additives.

6. Seawater/freshwater gel fluids are inhibitive muds used in early drilling to provide fluid control, shear thinning, and lifting properties for removing cuttings from the hole. Prehydrated bentonite is used in both seawater and freshwater fluids and attapulgite is used in seawater when fluid loss is not a concern.

7. Lightly treated lignosulfonate freshwater/seawater fluids resemble seawater/ lignosulfonate muds except their salt content is less. The viscosity and gel strength of this mud are controlled by lignosulfonate or caustic soda.

8. Lignosulfonate freshwater fluids are similar to the muds at #2 and #7 except the lignosulfonate content is higher. This mud is used for higher temperature drilling.

The chemical characterization of drilling fluids used in the Gulf of Mexico is based on the composition of these generic drilling fluids, a study conducted for PESA, and the analyses submitted under the Diesel Pill Monitoring Program (DPMP) as part of the NPDES general permit for OCS activities (U.S. EPA and API, 1985). The whole effluent metal concentrations are presented in Table 3-2. Organics concentrations from the Diesel Pill Monitoring Program data are presented in Table 3-3.

3.3   DRILL CUTTINGS

Drill cuttings are fragments of the geologic formation broken loose by the drill bit and carried to the surface by the drilling fluids that circulate through the borehole. They are composed of the naturally occurring solids found in subsurface geologic formations. Cuttings are removed from the drilling fluids by a shale shaker and other solids control equipment (SCE) before the fluid is recirculated down the hole.

The shale shaker, a vibrating screen, removes large particles from the fluid. If the shaker is damaged or a bypass problem occurs, the cuttings are removed by gravitational settling. A series of SCE components progressively remove finer and finer particles. SCE components include desolvers, desilters, and centrifuges.

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Table 3-2. Whole Mud Metal Concentrations (mg/l Whole Mud)

	Data Set[a]	Minimum	Mean	U 95%	Maximum
Antimony	3	<.427	3.59	4.94	24.12
Arsenic	1	.028	6.58	11.1	16.7
	3	.843	14.86	23.1	255
	Avg.		12.8	20.1	
Beryllium	3	.12	32.3	651	1,913
Cadmium	1	<.00324	.315	.651	1.82
	2	.066	2.72	4.47	9.92
	3	.16	4.52	8.44	129
	Avg.		3.31	6.06	
Chromium	1	<.162	539	879	1,200
	2	13.7	400	602	1,268
	3	15.6	368	420	688
	Avg.		408	549	
Copper	1	.092	37.1	66.2	127
	2	4.93	319	860	3,077
	3	2.57	39.6	59.2	602
	Avg.		99.4	233	
Lead	1	.459	10.2	16.6	27.5
	2	29.1	99.7	138	244
	3	10.3	54.7	69.3	243
	Avg.		55.7	73.8	
Mercury	1	<.00054	.309	.468	.729
	3	.004	.54	.737	4.23
	Avg.		.482	.670	
Nickel	1	<3.24	2.9	5.57	14.8
	3	1.05	14.4	20.2	155
	Avg.		11.5	16.5	
Selenium	1	.08	.82	1.16	<3.44
	3	.104	.45	.57	3.15
	Avg.		.542	.717	

[a] Data Set 1 - Generic Drilling Fluids
   Data Set 2 - PESA Muds
   Data Set 3 - DPMP

(continued)

Table 3-2. Whole Mud Metal Concentrations (mg/l Whole Mud) (continued)

	Data Set[a]	Minimum	Mean	U 95%	Maximum
Strontium	2	39.4	322	520	1,250
Silver	1	<.00324	.315	.651	1.82
	3	.019	.647	.62	4.05
	Avg.		.564	.627	
Thallium	1	<.00324	.112	.18	.317
	3	.032	.38	.456	1.71
	Avg.		.313	.387	
Zinc	1	.429	46.6	76.1	140
	2	45.5	461	767	1,735
	3	8.45	162	194	484
	Avg.		204	294	

Table 3-3. Whole Mud Organic Pollutant Concentrations from DPMP Data (mg/l)

	Acenaphthene		Cl-Benzene		Ethyl-Benzene		Naphthalene	
	MB[a]	MA[b]	MB	MA	MB	MA	MB	MA
Incidence	1/8	2/8	1/8	2/8	3/8	7/8	5/8	7/8
Min.	11.3	1.32	0.365	2.29	2.46	0.727	5.23	9.46
Mean	11.3	3.17	0.365	2.68	4.67	7.78	20.8	39.4
Wtd. Avg.	1.41	0.791	0.0456	0.670	1.75	5.96	13.0	34.4
U95%	11.3	6.79	0.365	3.44	8.64	11.7	34.9	57.2
Max.	11.3	5.01	0.365	3:07	8.72	15.7	47.6	76.0
Mud w/o Oil (<0.5%)								
Incidence	0/3		0/3		0/3		0/3	
Avg.	0		0		0		0	
Wtd. Avg.	0		0		0		0	
Mud w/Oil (>0.5%)								
Incidence	3/13		3/13		8/13		12/13	
Avg.	5.88		1.91		8.56		31.6	
Wtd. Avg.	1.36		0.44		5.27		29.2	

	Phenol		Toluene		PAH (sum)	
	MB	MA	MB	MA	MB	MA
Incidence	1/8	0/8	3/8	7/8	5/8	8/8
Min.	1.37	0	0.04	0.715	82.9	34.5
Mean	1.37	0	1.5	5.46	200	360
Wtd. Ave.	0.171	0	0.563	4.77	125	360
U95%	1.37	0	3.14	7.92	335	360
Max.	1.37	0	2.93	10.6	457	760
Mud w/o Oil (<0.5%)						
Incidence	0/3		1/3		0/3	
Avg.	0		0.04		0	
Wtd. Avg.	0		0.01		0	
Mud w/Oil (>0.5%)						
Incidence	1/13		9/13		13/13	
Avg.	1.37		4.74		299	
Wtd. Avg.	0.105		3.28		299	

[a] MB - Mud before pill
[b] MA - Mud after pill

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After removal, the cuttings are discharged from the rig near or below the water surface. The solids discharged at this point mainly consist of: drill cuttings, wash solution, and drilling mud that still adheres to the cuttings. The cuttings, when discharged, can contain as much as 60% by volume drilling fluids (U.S. EPA, 1985). The composition of a shale-shaker discharge is presented in Table 3-4.

The rate of discharge of drill cuttings can vary from 1 to 10 bbl/hr. Discharge is greater when the well is shallower as drilling is faster and a larger bit is used. Over the life of a well, 3,000 to 6,000 bbl of wet solids are discharged from the SCE (Ayers, 1981).

3.4   DECK DRAINAGE

The permit defines deck drainage as waste resulting from platform washings, deck washings, work area spills, rainwater, and runoff from curbs, gutters, and drains, including drip pans and wash areas. The runoff collected as deck drainage also may include detergents used in deck and equipment washing. Tank cleaning discharges are included in some EPA Region 9 permit definitions (U.S. EPA, Region 9, 1985).

In deck drainage, oil and detergents are the pollutants of primary concern. During drilling operations, spilled drilling fluids also can end up as deck drainage. Acids (hydrochloric, hydrofluoric, and various organic acids) used during workover operations may also contribute to deck drainage, but generally these are neutralized by deck wastes and/or brines prior to disposal.

A typical platform-supported rig is equipped with pans to collect deck and drilling floor drainage. The drainage is separated by gravity into waste material and liquid effluent. Waste materials are recovered in a sump tank, then treated and disposed, returned to the drilling mud system, or transported to shore. The liquid effluent, primarily washwater and rain water, is discharged.

3.5   PRODUCED WATER

Produced water (also known as production water, process water, formation water, or produced brine) is the water brought up from the hydrocarbon-bearing strata with the produced oil and gas. Produced water includes small volumes of treating chemicals that return to the surface with the produced fluids and pass through the produced water system. It constitutes a major waste stream from offshore oil and gas production activities.

Table 3-4. Mineral Composition of a Shale-Shaker Discharge from a Mid-Atlantic Well[a]

Mineral	Percentage by Weight (Dry Basis)
Barium Sulfate	3
Montmorillonite	21
Illite	11
Kaolinite	11
Chlorite	6
Muscovite	5
Quartz	23
Feldspar	8
Calcite	5
Pyrite	2
Siderite	4

[a] 65% solids, density 1.7 g/cm^3.

Source: Adapted by NRC (1983) from Ayers et al. (1980b).

Produced water is composed of formation water that is brought to the surface combined with the oil and gas, injection water (if used for secondary oil recovery and has broken through into the oil formation), and various added chemicals (biocides, coagulants, corrosion inhibitors, etc.). The constituents include dissolved, emulsified, and particulate crude oil constituents, natural and added salts, organic and inorganic chemicals, solids, and trace metals. Chemicals used on production platforms such as biocides, coagulants, corrosion inhibitors, cleaners, dispersants, emulsion breakers, paraffin control agents, reverse emulsion breakers, and scale inhibitors may also be present. The results of chemical analyses of three produced water data sets are presented in Table 3-5.

Produced waters can be classified into three groups--meteoric, connate, and mixed waters--depending on its origin. Meteoric water is water that originates as rain and fills porous or permeable shallow rocks or percolates through them along bedding planes, fractures, and permeable layers. Carbonates, bicarbonates, and sulfates in the produced water indicate meteoric water that has come from the surface. Connate water is the water in which the marine sediments or the original formation was deposited. It comprises the interstitial water of the reservoir rock and is characterized by chlorides, mainly sodium chloride, and high concentrations of dissolved solids. Mixed waters have both high chloride and sulfate-carbonate-bicarbonate concentrations suggesting meteoric water mixed or partially displaced by connate water (MMS, 1982).

The salinity and chemical composition vary from different strata and different petroleum reserves. Salinity of produced water usually ranges between 75 and 225 g/kg compared to seawater at 35 g/kg (Boesch, 1988). Produced water generally contain little or no dissolved oxygen and the water may contain high concentrations of total organic carbon and dissolved organic carbon, primarily in the form of volatile aromatic hydrocarbons and aliphatic hydrocarbons, due to the water being intermingled with petroleum (Boesch and Rabalais, 1989).

Produced waters have also been found to include radioactive materials such as radium. Normal surface waters in the open ocean contain 0.05 pCi/liter of radium. Radionuclide data from Gulf coast drilling areas show Ra-226 concentrations of 16 to 393 pCi/liter and Ra-228 concentrations of 170 to 570 pCi/liter. Filtered produced water radium levels are slightly lower (U.S. EPA, 1978).

Produced water production rates depend on the method of recovery used and the formation being drilled. Discharge rates can vary from none at some platforms to large quantities from central processing facilities. An EPA 30 platform study reports estimated discharge rates at 134 bbl/day to 150,000 bbl/day for offshore platforms in the Gulf of Mexico.

Table 3-5. Analyte Concentrations from Produced Water Data Sets

Analyte	Data Set[a]	Concentration (mg/l)			
		Minimum	Mean	U 95%	Maximum
Acenaphthene	3	.002	.006	--	.010
Arsenic	1	.001	.013		.030
	2	.404	.452	.039	.500
	Avg.[b]	.071	.103	.518	
Benzene	1	.054	16.9	83.9	150.0
	2	1.18	2.12	3.17	3.21
	3	.140	1.29	--	12.04
	Avg.		14.8	72.8	
Cadmium	1	.001	.057	.230	.350
	3	.098	.098		.098
Chromium	1	.010	.218	.906	1.20
Copper	1	.010	.184	1.01	1.80
	3	.008	.024	--	1.45
Cyanides	1	.01	.01	.01	.01
Ethylbenzene	2	.145	.227	.241	(.430)
	3	.019	.098	--	6.01
Lead	1	.001	.544	2.56	4.20
	3	.223	2.96	--	5.70
Naphthalene[c]	1	.010	.511	.828	4.20
	2	.0669	.154	.258	.307
	3	.026	.126	--	1.18
	Avg.		.466	.757	
Mercury	1	.001	.004	.007	.005
	2	.0004	.0004	.0004	.0004
	Avg.		.0035	.0061	

(continued)

[a] Data Set 1 - 40 platform survey, Texas RR Commission permits
Data Set 2 - 7 platform survey, U.S. EPA, 1987b
Data Set 3 - 30 platform survey, U.S. EPA, 1985
[b] The average value is the weighted average of data sets 1 and 2.
[c] The concentration for naphthalene in data set 1 is based on the reduction of three data points by a factor of 1000, assuming that errors were made on the lab report, making these values more comparable to other data. The average and U95% naphthalene values for data set 1, if these values are included as reported, were 9.49 mg/l and 68.0 mg/l, respectively.

Table 3-5. Analyte Concentrations from Produced Water Data Sets (continued)

Analyte	Data Set[a]	Concentration (mg/l)			
		Minimum	Mean	U 95%	Maximum
Nickel	1	.01	.661	2.09	2.50
	3	.072	.138	--	.216
Pentachlorophenol	3	.002	.002	--	.002
pH	1	5.50	6.70	7.72	7.63
	2	5.97	6.79	7.34	7.80
Phenols	1	.056	13.3	66.8	130.0
	2	.153	2.86	5.17	6.33
	3	.065	.885	--	20.81
	Avg.		11.9	58.9	
Phosphorus	2	.554	.735	.986	.917
PAH[d]	1	.010	.511	.828	4.20
	2	.0827	.281	.512	.682
	3	.064	.183	--	1.26
	Avg.		.482	.788	
Selenium	1	.001	.243	.693	.500
Silver	1	.130	.193	.316	.300
	2	.500	.500	.500	.500
	Avg.		.237	.342	
Toluene	2	.953	1.84	2.85	3.52
	3	.104	1.07	--	12.54
Zinc	1	.010	1.69	12.93	31.0
	2	.031	.179	.309	.440
	3	.027	.094	--	.445
	Avg.		1.48	11.1	

[d] PAHs are presented in this table as a sum of those PAHs that were analyzed separately. They include: acenaphthene, anthracene, benzo(a)pyrene, 3,4-benzofluoranthene, 11,12-benzofluoranthene, dibenzo(a,h)anthracene, fluorene, naphthalene, 3-methylcholanthrene, 7,12-dimethylbenz(a)anthracene, phenanthrene, 2-methylnaphthalene, 2-chloronaphthalene, 3,3-dichlorobenzidine, biphenyl, 4-aminobiphenyl, phenothiazine, benzidine, 4-nitrobiphenyl, thianaphthalene, 3,3-dimethylbenzidene, pyrene, dibenzofuran, dibenzothiophene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene, perylene, 4,5-methylene phenanthrene, benzo(b)fluoranthene, fluoranthene, benzo(k)fluoranthene, acenaphthylene, triphenylene, chrysene, 2,3-benzofluorene, 1-phenylnaphthalene, 2-(methylthio)benzothiazole, 1-methylphenanthrene, 3,6-dimethylphenanthrene, 1-methylfluorene, 2-isopropylnapthalene, 1,5-naphthalenediamine. Only those values reported above the detection limit were included.

After treatment in an oil-water separator, produced water is usually discharged into the sea, or in some cases is reinjected for disposal or pressure maintenance purposes. Produced water from the last stage of processing typically contains several hundred to perhaps a thousand or more parts per million of oil (U.S. EPA, 1985).

3.6 PRODUCED SAND

Produced sand is the material removed from the produced water. Produced sand also includes desander discharge from the produced water waste stream and blowdown of water phase from the produced water treating system. Sands that are finer and of low volume may be drained into drums on deck or carried through the oil-water treatment system and appear as suspended solids in the produced water effluent, or they may be settled out in treatment vessels. If sand volumes are larger and sand particles coarser, the solids are removed in cyclone separators, thereby producing a solid-phase waste. The sand that drops out in these separators is generally contaminated with crude oil (oil production) or condensate (gas production) and requires washing to recover the oil. The sand is washed with water combined with detergents, or solvents. The oily water is directed to the produced water treatment system or to a separate oil-water separator to become part of the produced water discharge following oil separation. The treated sand is discharged overboard, or hauled to shore for land disposal.

3.7 SANITARY WASTES

The sanitary wastes discharged offshore are human body wastes from toilets and urinals. The volume and concentrations of these wastes vary widely with time, occupancy, platform characteristics, and operational situations. Usually the toilets are flushed with brackish water or seawater. Due to the compact nature of the facilities, the wastes have less dilution water than common municipal wastes. This creates greater waste concentrations. Some platforms combine sanitary and domestic waste waters for treatment; others maintain sanitary wastes separate for chemical or physical treatment by an approved marine sanitation device.

3.8 DOMESTIC WASTES

Domestic wastes (gray water) originate from sinks, showers, safety showers, eye wash stations, laundries, food preparation areas, and galleys on the larger facilities. This waste stream usually does not receive any treatment before discharge.

3.9 COMPLETION FLUIDS

Completion fluids are salt solutions, weighted brines, polymers, and various additives used to prevent damage to the well bore during operations which prepare the drilled well for hydrocarbon production. These fluids move into the formation and return to the surface as a slug with the produced water. Drilling muds remaining in the wellbore during logging, casing, and cementing operations or during temporary abandonment of the well are not considered completion fluids and are regulated as drilling fluids discharges.

Well completion occurs if a commercial-level hydrocarbon reserve is discovered. Completion of a well involves setting and cementing the casing, perforating the casing and surrounding cement to provide a passage for oil and gas from the formation into the well bore, installing production tubing, and packing the well. Completion fluids are used to plug the face of the producing formation while drilling or completion operation are conducted in hydrocarbon-bearing formations. They prevent fluids and solids from passing into the producing formation, thereby reducing its productivity or damaging the oil or gas.

The production zone is a porous rock formation containing the hydrocarbons, either oil or gas, and can be damaged by mud solids and water contained in drilling fluids. The completion fluids create a thin film of solids over the surface of the producing formation without forcing the solids into the formation. A successful completion fluid is one that does not cause permanent plugging of the formation pores. The composition of the completion fluid is site-specific depending on the nature of the producing formation.

3.10 CEMENT

In order to protect the well from being penetrated by aquifers, it is necessary to install a casing in the bore hole. The casing is installed in stages of successively smaller diameters as the drilling progresses. The casings are cemented in place after each installation.

A cement slurry is mixed on site and is pumped through a special valve at the well head through the casing to the bottom and up the annular space between the bore hole wall and the outside of the casing to the surface. The cement is allowed to harden and drilling is resumed.

Most wells are cemented with an ordinary Portland cement slurry. The amount of cement used for each well depends on the well depth and the volume of the annular space. Additives are used to compensate for site-specific temperature and salt water conditions.

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3.11 WORKOVER FLUIDS

Workover fluids are salt solutions, weighted brines, polymers and other specialty additives used in a producing well to allow safe repair and maintenance or abandonment procedures. High solids drilling fluids used during workover operations are not considered workover fluids by definition and therefore must meet drilling fluid effluent limitations before discharge may occur. Packer fluids, low solids fluids between the packer, production string, and well casing, are considered to be workover fluids and must meet only the effluent requirements imposed on workover fluids.

Workover fluids are put into a well to allow safe repair and maintenance, for abandonment procedures, or to reopen plugged wells. During repair operations, the fluids are used to create hydrostatic pressure at the bottom of the well to control the flow of oil or gas and to carry materials out of the well bore. To reopen wells, fluids are used to stimulate the flow of hydrocarbons. Both of these operations must be accomplished without damaging the geologic strata.

To reopen or increase productivity in a well, hydraulic fracturing of the formation may be necessary. Hydraulic fracturing is achieved by pumping fluids into the bore hole at high pressure, frequently exceeding 10,000 psi. Proper fracturing accomplishes the following:

- Creates reservoir fractures thereby improving the flow of oil to the well
- Improves the ultimate oil recovery by extending the flow paths, and
- Aids in the enhanced oil recovery operation.

Over a period of time the fractures may close up. Materials can be introduced into the fissures to keep them open. Typical materials used include sand, ground walnut shells, aluminum spheres, glass beads, and other inert particles. These "propping agents" are carried into the fractures by the workover fluid.

Acid stimulation of a well is achieved by pumping an acid solution down the well and forcing the solution into the producing formation. The primary purpose of acid treatment is to dissolve the rock, thereby creating larger openings that allow increased oil flow. The most common type of acid treatment also results in the fracture of the formation with the acid acting as both the fracturing and dissolving medium. "Matrix acidizing" consists of pumping the acid at a pressure low enough to avoid fracturing the formation. The formations most often acidized are those of limestone or dolomite.

Specialty additives have been developed for well stimulation. Typical chemicals used in well stimulation are polymers, acid salts, acetic acid, and acid/oil emulsions. The additives inhibit the acid treatment fluids to minimize acid attack on the well casing and piping. Surfactants, sequestering agents, gelling agents, and suspending agents also may be used, depending on the field conditions. Most of these materials are destroyed or diluted by the formation or formation waters before any possible release to the environment. Those that are not destroyed often remain in the formation.

3.12 BLOWOUT PREVENTER FLUIDS

A vegetable or mineral oil solution or antifreeze (polyaliphatic glycol) is used as a hydraulic fluid in BOP stacks while drilling a well. The blowout preventer may be located on the seafloor, and is designed to contain pressures in the well that cannot be maintained by the drilling mud. Small quantities of BOP fluid are discharged periodically to the seafloor during testing of the blowout preventer device.

3.13 DESALINATION UNIT DISCHARGES

This is the residual high-concentration brine discharged from distillation or reverse-osmosis units used for producing potable water and high-quality process water offshore. It has a chemical composition and ratio of major ions similar to seawater, but with high concentrations. This waste is discharged directly to the sea as a separate waste stream.

3.14 BALLAST WATER

Ballast and storage displacement water are used to stabilize the structures while drilling from the surface of the water. Two types of ballast water are found in offshore producing areas (tanker and platform ballast). Tanker ballast water would not be covered under an NPDES permit.

Platform stabilization (ballast) water is taken on from the waters adjacent to the platform and may be contaminated with stored crude oil and oily platform slop water. Newly designed and constructed floating storage platforms use permanent ballast tanks that become contaminated with oil only in emergency situations when excess ballast must be taken on. Oily water can be treated through an oil-water separation process prior to discharge.

Storage displacement water from floating or semi-submersible offshore crude oil structures is mainly composed of seawater. Much of its volume can usually be discharged directly without treatment. Water that is contaminated with oil may be passed through an oil-water separator for treatment.

3.15 BILGE WATER

Bilge water, which seeps into all floating vessels, is a minor waste for floating platforms. This seawater becomes contaminated with oil and grease and with solids such as rust where it collects at low points in vessels. This bilge water is usually directed to the oil-water separator system used for the treatment of ballast water or produced water, or it is discharged intermittently.

3.16 UNCONTAMINATED SEAWATER

Seawater used on the rig for various reasons is considered uncontaminated if chemicals are not added before it is discharged. Included in this discharge are waters used for fire control equipment and utility lift pump operation, pressure maintenance and secondary recovery projects, fire protection training, pressure testing, and non-contact cooling.

3.17 BOILER BLOWDOWN

Boiler blowdown discharges consist of water discharged from boilers as is necessary to minimize solids build-up in the boilers, including vents from boilers and other heating systems.

3.18 SOURCE WATER AND SAND

Discharges of source water and sand consist of water from non-hydrocarbon bearing formations used for the purpose of pressure maintenance or secondary recovery, including the entrained solids.

4. TRANSPORT AND PERSISTENCE

4.1 DRILLING FLUIDS

Drilling fluids contain quantities of coarse material, fine material, dissolved solids, and free liquids. Upon discharge, this mixture separates rapidly. An upper plume is formed from shear forces and local turbulent flow at the discharge pipe. This plume will migrate to its level of neutral buoyancy while particulates slowly settle to the bottom. This plume is advected with prevailing currents. The fine solids settle at a rate depending on aggregate particle size, which therefore is very dependent on flocculation. This upper plume contains about five to seven percent, by weight, of the total drilling fluid discharge (Ayers et al., 1980b).

A lower plume contains the majority of discharged materials. Coarser materials fall rapidly out of the bottom of the lower plume, with a transit time so brief that the influence of current is minimal. Ayers et al. (1980b) found that the lower plume components deposit on the bottom within a few meters from the discharge point. If water depths are great enough to prevent bottom impact, the lower plume also will reach its level of neutral buoyancy. Fine particulates within the lower plume will be advected with ambient current flow, similar to their behavior in the upper plume.

Both upper and lower plumes are affected by three different transport processes or pathways: physical, chemical, and biological. Physical transport processes affect concentrations of discharge components in the water column through dilution, dispersion, and settling. Physical processes include currents, turbulent mixing, settling, and diffusion. These processes include current speed and direction, tidal regime, kinetic energy availability, and the characteristics of the receiving water such as density stratification. Physical processes are the most understood of the three transport pathways.

Chemical and biological processes produce changes in the structure and/or speciation of materials that affect their bioavailability and toxicity. Chemical processes include the dissolution of substances in seawater, particle flocculation, complexing of compounds that may remove them from the water column, redox/ionic changes, and absorption of dissolved pollutants on solids. Biological processes include bioaccumulation in soft or hard tissues, fecal agglomeration and settling of materials, and physical reworking to mix solids into

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the sediment (bioturbation). Fecal agglomeration and settling of materials and bioturbation will be discussed in this section. Bioaccumulation is covered in Section 5.

4.1.1 Physical Transport Processes

Pollutant concentrations resulting from offshore platform discharges are influenced by several factors related to the discharge and the medium into which it is released. Discharge-related factors include the solids content of the effluent, distribution of particle sizes and their settling rates, effluent chemical composition, discharge rates and duration, and density.

Environmental factors that affect dispersion and transport of discharged materials include speed, direction, and variability of currents, tidal influences, wave action, wind regime, topography of the ocean bottom, bottom currents, and turbulence caused by platform wake. These factors influence dispersion of effluents in the water column, and resuspension and transport of solids settled on the seafloor. Areas of high hydrodynamic energy will disperse discharges more rapidly than less energetic areas.

Current direction determines the predominant location of potential impacts, while current speed influences the extent of area affected. Velocity and boundary conditions also affect mixing because turbulence increases with current speed and proximity to the seafloor. Currents and turbulence can vary markedly with location and site characteristics and can affect the movement as well as concentration of suspended matter, and the entrainment, resuspension, and advection of sedimented matter.

Houghton et al. (1980; 1981) indicate that turbulence induced by submerged portions of the drilling platform may also significantly contribute to the dispersion of the muds. The study attributes increased dispersion of discharged materials at a Cook Inlet platform to rig-induced turbulence. Houghton et al. (1981) concluded that turbulence became a major source of dispersion when current speeds ranged from 5 to 10 cm/sec (0.16 to 0.32 ft/sec) or greater. However, this wake-effect has not been systematically studied at other locations. Ray and Meek (1980), for example, observed little change in plume dilution at Tanner Bank with velocity variations between 2 and 45 cm/sec (0.076 and 1.48 ft/sec).

Physical Transport Processes Affecting the Upper Plume

The materials contained in the upper plume may be subjected to immediate wake-induced turbulence, and are then influenced by dispersion processes. These materials are transported at the speed and direction

of prevailing current. Sinking rates of solids in the upper plume will largely depend on the following four factors:

- Discharged material properties
- Characteristics of receiving waters
- Currents and turbulence
- Flocculation and agglomeration.

The physical properties of the discharged materials affect mixing and sedimentation. For suspended clay particulates, particle size and both physical and biological flocculation will determine settling rates. While oil exhibits little tendency to sink, it has displayed the ability to flocculate clay particles and to adsorb to particulates and sink with them to the bottom (Middleditch, 1980).

One of the major receiving water characteristics influencing plume behavior is density structure and stratification. Density stratification contributes to the dissipation of dynamic forces in the dynamic collapse phase of the plume, which represents the point at which passive diffusion and settling of the individual particles become the predominant dispersive mechanisms. Density stratification may concentrate certain components along the pycnocline. If flocculation produces particles large enough to overcome the barrier, settling will continue. If density stratification is weak or the pycnocline is above the discharge point, it may not affect plume behavior.

Ecomar (1978), as reported in Houghton et al. (1981), noted that upper plumes in the Gulf of Mexico follow major pycnoclines in the receiving water. A similar finding has been observed by Trefry et al. (1981), who traced barium levels along pycnoclines. This type of transport is a potential concern because sensitive life stages of planktonic, nektonic, and benthic organisms may collect along the pycnocline. Ayers et al. (1980a) observed that the bottom of the upper plume followed a major pycnocline after drilling fluid discharges at rates of 275 bbl/hr and 1,000 bbl/hr in the Gulf of Mexico.

Flocculation and agglomeration affect plume behavior by increasing sedimentation rates as larger particles are formed. Flocculation is enhanced in salt or brackish waters due to increased cohesion of clay particles (Meade, 1972). Agglomeration also occurs when larger particles are formed from a number of smaller ones through the excretion of fecal pellets by filter-feeding organisms.

Most studies of upper plume behavior have measured particulate components and paid less attention to the liquid and dissolved materials present. Presumably, these latter components are subject to the same

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physical transport processes as particulate matter, with the exclusion of settling. Studies suggest that suspended solids in the upper plume may undergo a higher dispersion rate than dissolved components.

Houghton et al. (1980) measured upper plume transport in Lower Cook Inlet, using a soluble, fluorescent dye (fluorescein) in current speeds of 41 to 103 cm/sec. The water depth at the site is 63 m (207 ft) but the plume never sank below 23 m (75 ft). From transmissometry data collected in the Gulf of Mexico, Ayers et al. (1980b) estimated upper plume volume and found that a 275 bbl/hr drilling fluid discharge exhibited a dilution ratio of 32,000:1 after 60 minutes and a 1,000 bbl/hr discharge showed a dilution ratio of 14,500:1 after 62 minutes. Dispersion ratios for suspended solids at these distances would be approximately one to two orders of magnitude greater than for soluble components.

Based on radiotracer data collected for offshore Southern California and Cook Inlet, Petrazzuolo (1983) estimates dilution rates of "soluble" tracers. The Cook Inlet data suggest that dilution rates may be comparable to, or at a rate of, approximately half that of dispersion (based on generalized estimates of distances to specified levels of dispersion; Table 4-1). These correlations may be confounded by dye-clay interactions, rendering this comparison more similar than would a true "soluble" component. The radiotracer data indicate that dilution could be 4 to 10 times less than dispersion (Table 4-2), based on dispersion/dilution estimates at specified distances. However, these data were obtained only from samples taken in the very near field (<100 m).

Physical Transport Processes Affecting the Lower Plume

The physical transport processes affecting the lower plume differ somewhat from those influencing the upper plume. The lower plume appears to have a component, composed of coarser material, that settles rapidly to the bottom regardless of current velocity. This rapid settling is most pronounced during high-rate bulk discharges in shallow waters. With the high downward momentum of these discharges, the plume reaches the bottom. At Tanner Bank, the lower plume was relatively unaffected by average currents of 21 cm/sec (0.69 ft/sec) and bottom surges of up to 36 cm/sec (1.18 ft/sec) (Ecomar, 1978).

The amount of fine solids settling to the bottom from the lower plume depends on collision and cohesion of clay particles, which in turn depends on suspended material concentration, salinity, and the cohesive quality of the material. Fine particles tend to flocculate more readily than larger particles. Houghton et al. (1981) cites earlier work by Drake (1976), which concluded that physical-chemical flocculation can increase settling rates an order of magnitude over rates for individual fine particles.

Table 4-1. Estimates of Distances Required to Achieve Specified Levels of Dispersions of a Soluble Drilling Fluid Tracer at Fixed Current Speeds[a]

Dispersion Criterion	Distance Required (m)[b] Current Speed (cm/sec)		
	5	10	15
10^4	10-17	19-34	29-51
10^5	80-146	169-291	240-437
5×10^5	355-657	709-1,313	1,063-1,970
10^6	673-1,256	1,345-2,512	2,018-3,768

[a] Adapted from Atlantic Richfield (1978) in Petrazzuolo (1983).
[b] Ranges in distances represent discharge rates of 21 to 1,200 bbl/hr.

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Table 4-2. Comparison of Radiotracer Dispersion versus Suspended Solids Dispersion and Rhodamine-Wt Dispersion[a]

Effluent	Distance (m)	Transport Time (min)	TB (10.0)[b] (^{3}H; ^{46}Sc)	TB (12.8) (TSS)	EPA/AEA (TSS)
Drilling Fluid (HTO)	0.31	0.245	3,130	2,570	2,635
Drill Cuttings (HTO)	0.31	0.06	940	640	571
	77	15.6	23,5000	163,644	254,822
Drilling Fluid (^{46}Sc)	3.8	3.07	11,100	32,204	42,657

[a] Adapted from Ecomar (1978), Auble et al. (1982); in Petrazzuolo (1983).

[b] Abbreviations: TB   - Tanner Bank; (values in parentheses indicate discharge rate in bbl/hr)
                     TSS - total suspended solids
                     HTO - tritiated water

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Presently, there are no water column sampling data for the lower plume. Its dynamics must be inferred from limited sediment trap data and from models of plume behavior (Brandsma et al., 1980).

Biological processes have been shown to increase settling rates for fine particles. Filter-feeding plankton ingest particles ranging from 1 to 50 um in diameter, and excrete them in fecal pellets ranging from 30 to 3,000 μm in size (Haven and Morales-Alamo, 1972, as in Houghton et al., 1981). Copepods have been cited as playing an important role in biologically induced fine particle agglomeration by Manheim et al. (1970), also as reported in Houghton et al. (1981).

4.1.2 Seafloor Sedimentation

Houghton et al. (1981) produced an idealized pattern for sedimentation around an offshore platform located in a tidal regime (Figure 4-1). Zero net current was assumed. The area of impact may have been overestimated from the true field case. Because no initial downward motion was assumed, longer settling times and greater plume dispersion were achieved. The result was an elliptical pattern, with the coarse fraction (10 mm-2 mm) deposited within 125 to 175 m of the discharge point, the intermediate fraction (250 μm-2 mm) deposited at 1,000 to 1,400 m, and the medium fraction (250 μm-74 μm) deposited beyond that distance. This is the greatest areal extent of bottom sedimentation for continuous discharges under the assumed conditions. Discontinuous discharges will be transported by currents at the time of release, and will form a starburst pattern over time (Zingula, 1975).

Studies have shown the extent of drilling fluid accumulation on the bottom to be inversely related to the energy dynamics of the receiving water. Vertical mixing also appears to be directly related to energy dynamics. Analysis of sediments at Tanner Bank showed no visible evidence of cuttings or mud accumulation 10 days after the last discharge, even though over 800,000 kg (882 short tons) of solids had been discharged over an 85-day period (Ray and Meek, 1980). Size analysis also indicated little change in the grain size distribution.

Low-energy environments, however, are not subject to currents removing deposited material from the bottom or mixing it into sediments. In the low-energy Mid-Atlantic environment, for example, Menzie (1982) reported that cuttings piles were visibly distinct one year after drilling had ceased. Zingula (1975) also reported visible cuttings pile characteristics in the Gulf of Mexico shortly after drilling had terminated.

One study in the Gulf of Mexico (Ayers et al., 1980b) examined the short-term sedimentation of drilling fluids and cuttings in 23 m of water. Sediment traps were deployed only to a distance of 200 m. No

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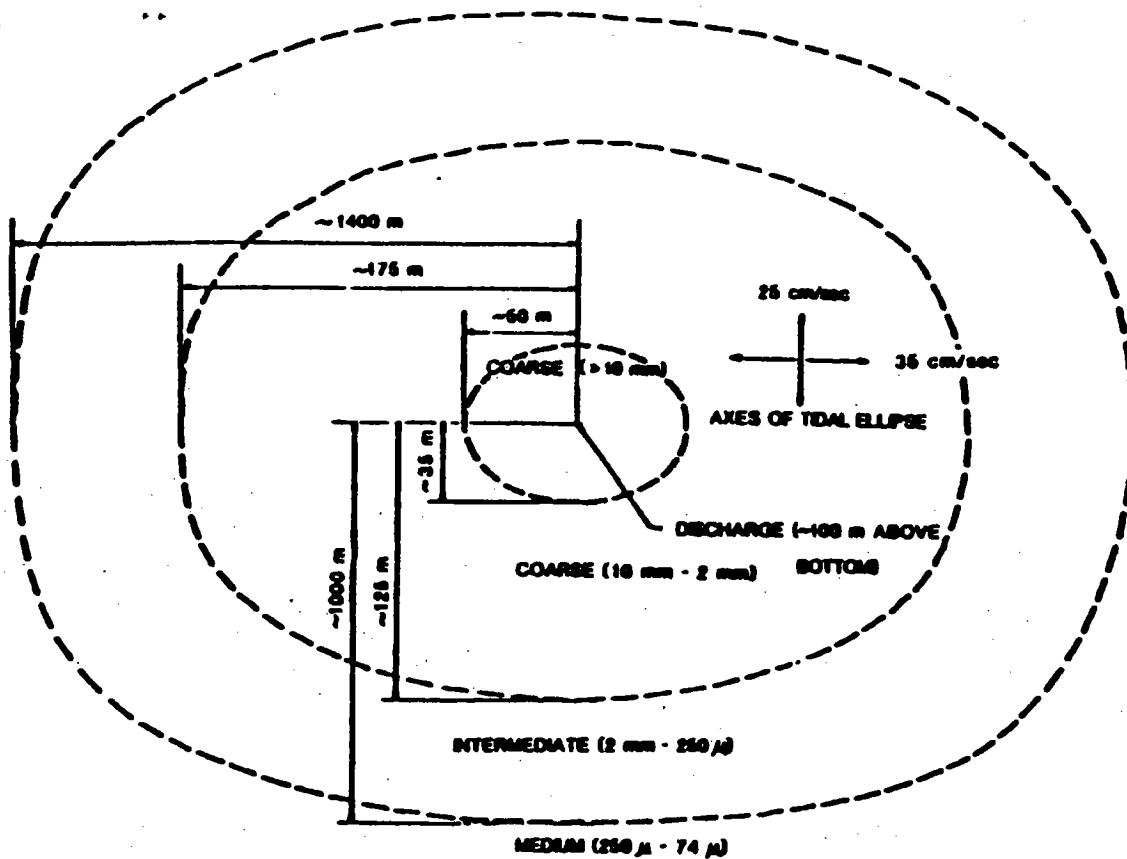
Figure 4-1. Approximate Pattern of Initial Particle Deposition
(Houghton et al., 1981)

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distance-dependent quantitative estimates were possible from the data. More material, 10 to 100 fold, was collected in traps after a 1,000 bbl/hr discharge than after a 275 bbl/hr discharge. The relative barium, chromium, and aluminum contents of collected matter was more similar to that found in the initially discharged fluid for the 1,000 bbl/hr discharge than for the 275 bbl/hr discharge. This suggests a reduced influence of differential dispersion of these metals during the higher rate discharge.

Vertical incorporation of plume components into sediments is caused by physical and biological reworking of sediments. The relative contributions of these processes to vertical entrainment has not been well-described. Petrazzuolo (1981; 1983) cites a Gulf of Mexico operation where barium concentration was substantially enriched to a 4-cm (1.6 in) depth at both 100-m (330 ft) and 500-m (1,600 ft) distances. The upper 2 cm (0.8 in) of sediment was highly enriched with barium. This study was conducted along one transect (not aligned with major current flows) after four wells had been drilled at the platform. Boothe and Presley (1985) describe sediment excess barium concentrations that penetrate to depths of 5 to 20 cm (up to 30 cm at 30 m from one well site), with penetration depth generally decreasing with distance from the well site.

4.1.3 Sediment Reworking

Another pathway of biological removal of pollutants involves benthic organisms reworking sediment and mixing surface material into deeper sediment layers. This process is known as bioturbation, and moves barite and clays from drilling mud to greater depths than they would otherwise achieve. Bioturbation can also expose previously buried materials, and could be an important factor in potential long-term impacts. No work was found to quantify bioturbation effects, although a few studies have observed organisms living on a cuttings pile or in the vicinity of drilling discharges (Menzie et al., 1980; Ayers et al., 1980b). However, if the environment is one which rapidly removes cuttings piles, or where physical forces dominate resuspension and reworking processes, then biological mixing activities may not prove significant.

4.1.4 Bioaccumulation

Bioaccumulation is the ability to concentrate naturally occurring substances, such as nutrients, or xenobiotics substances, to levels above ambient concentrations. Laboratory studies have shown that bioaccumulation of trace metals can be partially reversed when an organism is transferred from a contaminated environment to a clean one. There generally occurs a decrease in pollutant concentration within the organism, referred to as "depuration."

The majority of research of metal accumulation from drilling activities has focused on barite (barium) and ferrochrome lignosulfonate (chromium). Liss et al. (1980) examined chromium accumulation in sea scallops. The study states that chromium was found not to concentrate in the abductor muscle, but to concentrate in the kidney. In general, most of these studies represent the results of exposures of small sample sizes, ranging from three to six individuals. McCulloch et al. (1980) noted the accumulation of chromium in clams and oysters after exposure to used drilling fluids, but little net accumulation after depuration in clean seawater.

In summary, U.S. EPA (1985) evaluated bioaccumulation data for drilling fluids and components and concluded the following:

1. Several metals can be accumulated, including barium, cadmium, chromium, lead, strontium, and zinc.

2. In terms of results, observations that militate against any significant potential for adverse effects are: enrichment factors are generally low (barium and chromium excluded), depuration release levels are high, and no gross functional alterations, resulting from metal accumulation following high exposures to drilling fluids or compounds, have been reported.

3. Such a conclusion is largely compromised by several other observations. Test results indicate that uptake kinetics are not simple, with saturation plateaus beyond the scope and predictive power of studies that have been conducted. Test design problems also contribute to equivocal interpretations and to poor utility in hazard assessment analyses. These design problems include the choice of inappropriate drilling fluid fractions as test substances, the use of only one effective exposure concentration for fluid solids exposures, and the choice of tissues for analyses that are inappropriate for the species.

4. Because of (a) the extreme persistence of metals, (b) the elevation of sediment metal levels resulting from drilling discharges, (c) the notable toxicity of some of the metals examined (cadmium and lead), and (d) the inability to estimate potential effects from environmentally realistic exposures, metals accumulation should be considered an area requiring further study.

4.1.5 Chemical Transport Processes

Chemical and biological transport of drilling fluids is poorly described. Much must be gleaned from general principles and studies of other related materials. Several broad findings are suggested, but the data for a quantitative assessment of their importance are lacking. Chemical transport will most likely arise from oxidation/reduction and reactions that occur in sediments. Changes in redox potentials will affect the speciation and physical distribution (i.e., sorption-desorption reactions) of drilling mud constituents.

Dissolved metals tend to form insoluble complexes through adsorption on fine-grained suspended solids and organic matter, both of which are efficient scavengers of trace metals and other contaminants. Laboratory studies indicate that a majority of trace metals are associated with settleable solids <8 um in size (Houghton et al., 1981).

Trace metals, adsorbed to clay particles and settling to the bottom, are subjected to different chemical conditions and processes than when suspended in the water column. These sorbed metals can be in a form available to bacteria and other organisms if located at a clay lattice edge or at an adsorption site (Houghton et al., 1981). If the sediments become anoxic, conversion of metals to insoluble sulfides is the most probable reaction, and the metals are then removed from the water column. Environments that experience episodic sediment resuspension favor metal release if reducing conditions existed previously in buried sediments; such current conditions also allow further exposure of organic matter complexes for further reduction and eventual release.

Alterations in Sediment Barium Levels

The long-term fate of discharge drilling fluids has been followed in several studies using sediment barium levels as a tracer. Four studies have been performed in the Gulf of Mexico from which data have been analyzed to estimate the dispersion of sediment barium.

The subsequent fate of deposited material depends primarily on the physical processes that resuspend and transport particulates or entrain them into the sediments. Biological or chemical factors could also be important in stabilizing or mobilizing the material on the seafloor (e.g., through covalent binding of sediments or bioturbation).

Analyses of sediment barium and trace metal concentrations have been used to examine nearfield fate of drilling fluids on the seafloor, e.g., the rate of dispersion of sedimented material. High concentrations of barium persistently found near a well site suggest a lower energy area, which favors deposition. If elevated levels cannot be found, even soon after drilling, resuspension and sediment transport have taken place and a higher energy environment is suggested.

At present, the area-wide, large-scale distribution of drilling discharges is difficult to predict. However, it can be surmised that a number of drilling operations associated with the development of a particular field could contribute to a general regional increase of drilling-related materials on the seafloor.

A series of power-law regression analyses were developed to relate average barium levels to distances from the discharge source (Petrazzuolo, 1983). These equations predicted the distance-dependent decreases in sediment barium levels that were obtained in four field studies. A multivariate analysis was used to estimate average sediment barium levels with respect to distance and number of wells. At locations of approximately 100 m to 30,000 m from a nine-well platform, this analysis suggested that sediment barium data collected early in the development phase of an operation may provide accurate predictions of sediment barium levels later in the operation.

Data from exploratory drilling operations have been used to examine deposition of metals resulting from drilling operations. These data indicate that several metals are deposited, in a distance-dependent manner, around platforms, including cadmium, chromium, lead, mercury, nickel, vanadium, and zinc.

These sediment metal studies, when considered as a group, suggest that the enrichment of certain metals in surficial sediments may occur as a result of drilling activities (Table 4-3). While confounding factors occur in most of these studies (i.e., seasonal variability and other natural and anthropogenic sources of metal enrichment), discharged drilling fluids and cuttings are probably not the only drilling-related source.

The only two metals clearly associated with drilling fluids that appear to be elevated around rigs or platforms are barium and chromium. A study in the Canadian Arctic found that mercury would be the best trace metal tracer of discharged fluids (Crippen et al., 1980). Examination of mercury levels in fluids and sediments for domestic operations is notably underrepresented in the studies that have been reviewed. The degree of similarity between Canadian and domestic operations has not been evaluated. However, the findings of the Netserk study (Crippen et al., 1980) and lack of information on domestic operations indicate that the relationship between drilling fluid discharges and sediment mercury levels should be further clarified.

Metals that appear to be elevated as a result of drilling activities, and are not solely related to drilling fluids, include cadmium, mercury, nickel, lead, vanadium, and zinc. Cadmium, lead, and zinc in drilling fluids are the result of the use of pipe dope or pipe thread compounds. Mercury, nickel, and zinc may originate from sacrificial anodes. Cadmium, lead, and vanadium may also originate from the release of oil in drilling operations. This release can result from burning, incidental discharges or spills from the rig or supply boat traffic, or use as a lubricant in drilling fluids. Vanadium also may derive from wearing of drill bits. In a Gulf of Mexico platform study, brine (formation water) discharges were identified as an additional potential source of metal contamination.

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Table 4-3. Summary of Sediment Trace Metal Alterations from Drilling Activities[a]

Location	Trace Metal								
	As	Cd	Cr	Cu	Hg	Ni	Pb	V	Zn
Gulf of Mexico, Mustang Island Area suspended sediment	ND[b]	-	+ (8-31x)	± (7-10x)	ND	-	-	± (6-25x)	-
surficial sediment	ND	+ (3-9x)	-	-	ND	-	-	-	+ (2.5-3.5x)
Gulf of Mexico, Mustang Island Area	ND	±	±	±	ND	±	-	-	ND
Central Gulf of Mexico	ND	+	+	+	ND	+	+	+	
Mid-Atlantic	-	-	-	-	BLD	+ (2.5x)	+ (4-4x)	+ (2-9.5x)	+ (4x)
Mackenzie River Delta	+ (1.2-2.5x)	+ (2-6x)	+ (4-7x)	ND	+ (1.2-15x)	ND	+ (1.5-2.2x)	ND	+ (11.7x)
Beaufort Sea	ND	+ (2-6x)	+ (1.4-2x)	±	-	ND	+ (1.2-2.6x)	ND	+ (1.2-1.4x)

[a]Adapted from Tillery and Thomas (1980); Mariani et al. (1980); Crippen et al. (1980) in Petrazzuolo (1983).

[b]Abbreviations:
ND - not determined
+ - increased levels (magnitude change in parentheses) related to drilling
- - decreased levels related to drilling
± - isolated increases, not a clearly distance-related pattern
BLD - below the level of detection

Although these metals were enriched in the sediment, enrichment factors were generally low to moderate, seldom exceeding a factor of 10. The spatial extent of this enrichment also was limited. Either of two cases occurred: enrichment was generally distributed but undetectable beyond 300-500 m, or enrichment was directionally based by bottom current flows and extended further (to about 1,800 m) within a smaller angular component.

These considerations suggest that exploratory activities will not result in environmentally significant levels of trace metal contamination. However, other factors, such as the intensity of exploratory activities, normal sediment loading, and proximity either to commercial shell fisheries or to subsistence populations, could alter this conclusion. Sediment trace metal levels resulting from development drilling operations need further clarification, especially relating to the dynamics and extent of sediment contamination.

Two attempts have been made to estimate spatial distribution of discharged material from a two-well operation in the Gulf of Mexico. One industry-sponsored analysis indicates that 49 percent of discharged barium is dispersed beyond a radius of 1,250 m from the platform (Mobil Oil Corporation, 1978). Another analysis of these data indicates that 78 percent of the barium is located within a 1,000-m radius, and essentially all of the barium (calculated as 111 percent) is located within 1,250 m.

Boothe and Presley (1985) conducted an extensive survey of sediment chemistries around six platforms in the Gulf of Mexico. They concluded that only a small fraction of the total barium discharged is present in sediments near the discharge site. They found only 1 - 1.5% of discharged barium within 500 m of the discharge at shallower sites (13 - 34 m) and only 9 - 12% at deeper sites (76 - 102 m). Similarly, within a 3 km radius, they accounted for 5 - 7% at the shallower sites and 47 - 84% at the deeper sites. Statistically significant barium enrichment ($\geq$ twice background) existed in surface sediments at 25 of the 30 control stations located at a distance of 3 km from the drill sites.

Sporadic elevations in sediment trace metals also were noted by Boothe and Presley. Mercury and lead were significantly correlated to barium at several sites; distance dependent decreases were noted at two sites for mercury and one site for lead. Significant increases were noted generally only out to 125 m from the site; however the trend indicated increases perhaps to 300 - 500 m. The large statistical variability of the trace metal data set make statistical inferences difficult.

The general conclusion of this study is that barium and probably other drilling fluid contaminants associated with the settleable fraction of drilling muds are relatively mobile. Thus, drilling discharges are expected to be spread over a large area (i.e., > 3 km from their discharge source) on time scales of a year or so. These data are consistent with other data that indicate drilling discharges can be distributed widely

(Continental Shelf Associates, 1983; Ng and Patterson, 1982; Bothner et al., 1983 as cited in Boothe and Presley, 1985).

4.2   DISCHARGE MODELING - DRILLING FLUIDS

Two sets of OOC Mud Discharge Model runs were conducted using a broad set of environmental and operational conditions that are relevant to Gulf of Mexico discharges. One set of model scenarios (TRI, 1988) is based on discharges in the Gulf of Mexico, into a water depth of five meters, under varied operational and seasonal conditions. These scenarios generally result in maximized dispersion and minimized dilution. The second set of OOC Mud Discharge Model scenarios were run previously for EPA Region 10 (Tetra Tech, 1984), and are based on a varied set of operational and environmental conditions for operations in Alaskan waters. Although this second set of model runs was intended for an analysis of mud discharges to Alaskan waters, many of these discharge scenarios are also appropriate to the present Gulf of Mexico analysis and have been included in this Gulf of Mexico effort. These two data sets describe dispersion and dilution of drilling fluid plumes under a broad set of environmental conditions.

An average case and a reasonable worst case were derived from these data sets for estimating water column concentrations of drilling fluid constituents. Average case estimates are based on averages of plume dispersion or dilution derived from the total data set. Reasonable worst cases are based on selecting the lower half of dispersion or dilution estimates and averaging this subset of the data. For water quality analyses, dilution and dispersion are estimated at the boundary of the mixing zone, defined as a 100-m radial distance from the discharge. This approach is used for water quality analyses (see Section 9 of this document) because such analyses are based on attaining specified concentrations of pollutants at a specified spatial boundary.

4.2.1   OOC Mud Discharge Model

The OOC Mud Discharge Model is the most general of the available drilling fluid plume models. It uses LaGrangian calculations to track material (clouds) settling out of a fixed pipe and a Gaussian formulation to sum the components from the clouds. The OOC model includes the initial jet phase, the dynamic collapse phase, and the passive diffusion phase of plume behavior.

The minimum waste stream data input requirements for the OOC Mud Discharge Model include effluent bulk density and particle size distribution. The dispersion of up to 12 drilling fluid particle size solid fractions (i.e., settling velocity fractions) can be followed. For each constituent particle fraction, its settling velocity and its fractional proportion of total solids must be input to the model. The OOC model requires the following operational data input: the depth of the discharge, diameter of the discharge pipe, discharge

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rate, and orientation of the discharge relative to ambient currents. Ambient environmental data input requirements of the OOC model include current, density stratification, and bathymetry.

Operational data are generally adequate to fulfill the data input needs for the OOC Mud Discharge Model. Waste stream input data requirements are adequately addressed by existing information, with the possible exception of settling velocities for drilling fluid solids fractions. Currently, these data are both extremely limited and a key model parameter. Existing settling velocity data are available for only a very few drilling muds. Thus, lacking data on many mud types and mud samples, it is difficult to know if the available data adequately represent drilling fluids in the general sense. And, as previously mentioned, the settling velocity profiles are a key parameter in the model. They form the basis for calculating the effect of gravitational setting of drilling fluid solids and any shift in the particle size distribution (i.e., settling velocity distribution) will have significant effects on the calculated behavior of the plume. Thus, although there are minimally adequate data to use the model, these data represent drilling fluids, in general, with poor confidence.

4.2.2 Derivation of Dispersion/Dilution Estimates

A set of shallow water OOC Mud Discharge Model runs have been conducted (TRI, 1988). Two types of drilling fluid were used: a high density mud and low density mud, respectively, 17.4 pounds per gallon and 10 pounds per gallon. The low density mud was considered a reasonable example for light weight muds, while the high density mud was considered to be a reasonable (not a worst case) example of high density mud. The 10 lb/gal mud settling velocity characterization was taken from Continental Shelf Associates (1985). The 17.4 lb/gal mud characterization of settling velocities was documented in Brandsma et al. (1983). The settling velocity characterizations for these muds are shown in Table 4-4. The 10 lb/gal mud had an initial total suspended solids concentration (TSS) at discharge of 263,200 mg/l while the 17.4 lb/gal discharge had an initial TSS of 1,441,000 mg/l.

Operational data specifications for these selected shallow water runs included the following: the discharge is located at the surface, into a water depth of 5 meters; a vertically downward discharge orientation; discharge rates of 100 bbl/hr and 1,000 bbl/hr; a port diameter of 8". The rates of discharge selected are considered to be reasonable upper and lower bounds for routine drilling mud discharges. The discharge pipe diameter used is considered to be a reasonable estimate of possible discharge pipe diameters used in offshore drilling operations, which are probably not less than about 6" in diameter nor more than about 14" in diameter. (Note: the larger the diameter of the effluent port, the less dispersion/dilution would occur, all else remaining constant.)

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Table 4-4. Settling Velocity Characterizations for Low Density and High Density Drilling Fluids[a]

Solid No.	Density (g/ml)	Volume Concentration (cu ft/cu ft)	Settling Velocity (ft/sec)
Solid Constituents of Low Density (10 lb/gal) Mud			
1	3.0	0.01228	3.50E-03
2	3.0	0.02544	1.30E-03
3	3.0	0.008773	4.20E-04
4	3.0	0.007018	8.30E-05
5	3.0	0.007895	1.00E-05
6	3.0	0.02632	9.00E-06

Solid No.	Density (g/ml)	Volume Concentration (cu ft/cu ft)	Settling Velocity (ft/sec)
Solid Constituents of High Density (17.4 Lb/gal) Mud			
1	3.959	0.0364	2.16E-02
2	3.959	0.0364	6.82E-03
3	3.959	0.04368	2.78E-03
4	3.959	0.0728	1.43E-03
5	3.959	0.1383	7.58E-04
6	3.959	0.0364	4.27E-04

[a] Source: Brandsma et al., 1983
Continental Shelf Associates, 1985

Current and salinity values are based on profiles derived from data gathered for the Strategic Petroleum Reserve sites at West Hackberry and Bryant Mound, which are located offshore Holly Beach, Louisiana and Freeport, Texas. Ambient conditions used for the simulations were developed from data supplied by Dr. Robert Randall of Texas A & M University. Current speed data are shown in Table 4-5, which is a monthly frequency table for current speeds near the West Hackberry Brine Disposal Site in the Gulf of Mexico (Kelly et al., 1983). The data from this table were converted to exceedance probabilities for each month. This process gave a lower 10th percentile speed of 3.2 cm/sec and a 50th percentile speed of 9.9 cm/sec. Salinity values are based on profiles that have been measured at these brine discharge sites in the Gulf of Mexico. Table 4-6 shows ambient density data as abstracted from Kelly et al., (1983). The strong stratification for July, 1983 was chosen to provide a contrast to the weak stratifications of the spring and fall seasons.

4.2.3 Model Results

Tables 4-7 and 4-8 show model predictions for all three seasons selected for analysis, and present dispersion and dilution values at two stages. Table 4-7 presents values for dispersion and dilution at the end of initial mixing (the beginning of the passive-diffusive phase). Table 4-8 shows dispersion and dilution values at the 100-meter boundary.

The average dilution at 100 m for the 11 model runs showing the least dilution was 212 dilutions. The average dispersion at 100 m for all model runs was 4,203; the average dispersion at 100 m for the 11 model runs showing the least dispersion was 788.

A series of OOC Mud Discharge Model runs previously conducted for Region 10 (Tetra Tech, 1984) is also included in the present analysis. A subset of model runs was selected from this previous modeling effort for inclusion in the present assessment. This subset of model runs was appropriate to the range of conditions of oil and gas operations in the Gulf of Mexico.

The selected subset of model runs used in the present analysis are those that are labelled Cases 3, 5, 6, 9, 10, 11, 12, 13, 14, 18, 19, and 20 in this earlier report (Tetra Tech, 1984). These runs included: discharge rates of 250 bbl/hr and 1,000 bbl/hr; water depths of 5 m to 40 m; and current speeds of 2-30 cm/sec (Table 4-9). Results are reported at various distances between 15 m and 100 m from the discharge (Table 4-10). To estimate average water column concentrations of drilling fluid pollutants within 100 m of the discharge, an approach comparable to that used for the shallow water data set was adopted: averaging the dilution of the plume at 15-m and 100-m distances from the discharge. This approach relies on the comparability

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Table 4-5. Joint Frequency Table of Current Speed for West Hackberry Brine Disposal Site
(Current Meter Site 'n'), 6.2 Meter Water Depth[a]

Month		Speed Range (cm/sec)								
	0-2	2-5	5-10	10-15	15-20	20-25	25-30	30-40	40+
5/81	2.7	12.0	26.1	25.4	12.8	7.9	5.4	6.7	1.1
6/81	2.6	9.3	25.3	25.1	13.3	7.1	7.2	7.5	2.5
7/81	5.4	17.5	31.2	23.8	14.2	5.5	1.7	0.7	0.0
8/81	9.9	17.2	33.7	21.0	13.2	5.0	0.0	0.0	0.0
9/81	18.5	33.9	35.1	7.3	1.9	0.6	1.2	1.5	0.0
10/81	14.4	9.3	33.0	16.7	16.7	6.0	3.7	0.0	0.0
11/81	9.7	23.9	33.1	16.5	7.9	4.2	4.0	0.7	0.0
12/81	5.5	16.7	21.0	24.1	15.1	9.9	3.0	3.0	1.9
1/82	7.0	15.9	32.4	21.8	14.1	4.2	2.2	2.3	0.3
2/82	6.2	15.5	28.2	23.8	15.3	6.5	2.6	1.8	0.0
3/82	2.2	6.1	19.7	22.4	18.0	8.3	12.2	7.1	4.1
4/82	2.4	10.3	23.6	18.3	14.2	14.3	9.3	7.4	0.3

[a] Source: Kelly et al., 1983.

Table 4-6. Ambient Density Stratification Values, West Hackberry Brine Disposal Site[a]

Season	Depth (m)	Temp (°C)	Salinity (o/oo)	Sigma-T
Spring	1.0	28.0	24.3	14.4
(June 8, 1981)	1.5	28.2	24.1	14.2
	4.5	27.9	26.3	16.0
Summer	1.0	30.7	21.8	11.7
(July 16, 1981)	1.5	30.7	21.8	11.7
	4.5	30.4	24.1	13.5
	5.5	29.8	25.8	15.0
Fall	1.0	19.5	30.5	21.5
(Dec 2, 1981)	1.5	19.6	30.5	21.5
	4.5	20.5	31.9	22.3
	5.5	20.4	32.0	22.4
Winter	1.0	9.8	25.9	20.0
(Jan 21, 1982)	1.5	9.6	26.1	20.1
	4.5	9.7	27.2	20.9
	5.5	10.5	28.3	21.6
Strongly	1.0	30.5	10.6	3.5
Stratified	1.5	30.4	10.6	3.5
(July 22, 1983)	4.5	28.8	22.0	12.4
	5.5	29.0	22.0	12.4

[a] Source: Kelly et al., 1983; data from Station 21, in 5.5 meters of water.

Table 4-7. Shallow Water OOC Mud Discharge Model Results: Initial Mixing[a]

Run No.	Season	Discharge Rate (bbl/hr)	Mud Weight	Current Speed (cm/sec)	Distance to End of Dynamic Phase (m)	Initial Mixing	
						Dispersion	Dilution
1	Spring	100	L	10	30.5	255	151
2	Spring	100	H	10	59.8	10293	241
3	Spring	1000	L	10	14.1	38	27
4	Spring	1000	H	10	13.1	179	54
5	Spring	100	L	3	32.5	217	107
6	Spring	100	H	3	20.6	10382	219
7	Spring	1000	L	3	1.7	24	26
8	Spring	1000	H	3	0.1	ND	ND
9	Summer	100	L	10	11.4	143	110
10	Summer	100	H	10	16.3	953	223
11	Summer	1000	L	10	35.0	46	28
12	Summer	1000	H	10	13.0	148	53
13	Summer	100	L	3	2.3	84	76
14	Summer	100	H	3	11.9	1732	202
15	Summer	1000	L	3	11.1	41	27
16	Summer	1000	H	3	0.1	ND	ND
17	Fall	100	L	10	37.6	282	157
18	Fall	100	H	10	64.8	9823	240
19	Fall	1000	L	10	14.0	37	27
20	Fall	1000	H	10	12.5	164	54
21	Fall	100	L	3	11.8	175	104
22	Fall	100	H	3	20.7	20411	234
23	Fall	1000	L	3	1.7	24	26
24	Fall	1000	H	3	0.1	ND	ND

[a] Source: TRI, 1988.

Abbreviations

Mud Weight: H = 17.4 lb/gal (TSS = 1,441,000 mg/l)
              L = 10.4 lb/gal (TSS = 263,200 mg/l)
Current speed: H = 10 cm/sec
                L = 3 cm/sec
Discharge rate: H = 1,000 bbl/hr
                 L = 100 bbl/hr
Dilution/Dispersion: ND = Not Determinable (plume hit the bottom at the point of discharge)

Table 4-8. Shallow Water OOC Mud Discharge Model Results: 100-m Boundary Mixing[a]

Run No.	Season	Discharge Rate (bbl/hr)	Mud Weight	Current Speed (cm/sec)	100 m Boundary Dispersion[b]	100 m Boundary Dilution[c]
1	Spring	100	L	10	1578	429
2	Spring	100	H	10	9080	2188
3	Spring	1000	L	10	198	62
4	Spring	1000	H	10	1584	386
5	Spring	100	L	3	1820	485
6	Spring	100	H	3	15461	3685
7	Spring	1000	L	3	522	138
8	Spring	1000	H	3	ND	ND
9	Summer	100	L	10	889	267
10	Summer	100	H	10	4644	318
11	Summer	1000	L	10	198	62
12	Summer	1000	H	10	1751	426
13	Summer	100	L	3	2414	625
14	Summer	100	H	3	11840	27
15	Summer	1000	L	3	582	152
16	Summer	1000	H	3	ND	ND
17	Fall	100	L	10	1088	314
18	Fall	100	H	10	10278	2469
19	Fall	1000	L	10	229	69
20	Fall	1000	H	10	1730	421
21	Fall	100	L	3	1949	516
22	Fall	100	H	3	19881	2870
23	Fall	1000	L	3	546	143
24	Fall	1000	H	3	ND	ND

[a] Source: TRI, 1988.
Abbreviations
  Mud Weight: H = 17.4 lb/gal (TSS = 1,441,000 mg/l)
                L = 10.4 lb/gal (TSS = 263,200 mg/l)
  Current speed: H = 10 cm/sec
                 L = 3 cm/sec
  Discharge rate: H = 1,000 bbl/hr
                  L = 100 bbl/hr
  Dilution/Dispersion: ND = Not Determinable (plume hit the bottom at the point of discharge)
[b] Average dispersion at 100 m = 4,203; Lower-half runs, average dispersion at 100 m = 788
[c] Average dilution at 100 m = 898; Lower-half runs, average dilution at 100 m = 212

Table 4-9. EPA Region 10 OOC Mud Discharge Model Run Characteristics[a]

Case Number	Depth, m	Rate, bbl/hr	Current, cm/sec
3	40	1,000	10
5	5	1,000	10
6	10	1,000	10
9	10	1,000	10 (9 lb/gal mud)
10	15	1,000	2
11	15	1,000	10
12	15	1,000	30
13	20	1,000	10
14	40	1,000	10 (minimum stratification)
18	5	250	10
19	15	250	2
20	15	250	10

[a] Source: Tetra Tech, 1984.

Table 4-10. EPA Region 10 OOC Mud Discharge Model Results[a]

Distance, m	Weighting Factor[b]	Case Number Dilutions [Dispersions]											
		3	5	6	9	10	11	12	13	14	18	19	20
15.2	231	185 [417]	39 [120]	52 [163]	68 [60]	61 [67]	72 [150]	68 [186]	43 [115]	202 [333]	55 [149]	188 [345]	157 [492]
30.5	699	-	41	-	-	127	280	-	-	-	152	430	468
45.7	1,857	679	-	318	110	-	-	147	682	797	-	-	-
61.0	2,791	-	152	-	-	478	371	-	-	-	613	1,073	1,416
100	6,279	1,285 [905]	200 [4810]	536 [1785]	168 [299]	1,218 [11,407]	526 [1748]	903 [752]	1,082 [1092]	1,186 [731]	1,040 [6109]	2,239 [8873]	2,538[c] [2558][d]
Average Dilution[e]		735	120	294	118	640	299	486	563	694	548	1,214	1,348

[a] Adapted from: Tetra Tech, 1984
[b] Derived from $(r_i^2 - r_{i-1}^2)$, where r_i = radial distance; geometrically represents the relative area of the concentric rings defined by the radial distances at which dilutions were calculated (from the OOC Model)
[c] Average dilution for all runs at 100 m = 1,077; average dilution of lowest six runs = 562
[d] Average dispersion for all runs at 100 m = 3,422; average dispersion of lowest six runs = 921
[e] Derived from $(D_{15.2} + D_{100})/2$; average of all runs = 588; lower half average = 311

between results at the end of initial mixing in the shallow water runs to the results obtained at 15 m in the subset of Region 10's OOC Mud Discharge Model runs. An analysis of this comparability showed that the distance to the end of initial mixing in the shallow water runs averaged 18.2 m, quite close to the 15 m distance used in the Region 10 model runs.

The results of the analyses from these two data sets are reasonably comparable (Table 4-11). As expected, dilution in the shallow water data set (average dilution at 100 m = 898) is less than the average dilution of the Region 10 OOC Mud Discharge Model data set (1,077 dilutions at 100 m). Similar results were obtained for the reasonable worst case estimates, based on the average dilution of the worst half of the model runs of these two data sets. Based on the data, the following estimates of plume behavior were used in the analyses of the present study. For plume dilution at 100 m, results from the shallow water data were used: average dilution was assumed to be 898 and reasonable worst case dilution to be 212.

4.3 PRODUCED WATER

The major processes affecting the fate of discharged produced water and associated chemicals include dispersion and advection, volatilization, and adsorption/sedimentation.

Hydrocarbons that become associated with sedimentary particles by adsorption can accumulate around production platforms, either settling to the seafloor through the water column or more directly through bottom impact of the discharge plume. Sediment contamination by produced water hydrocarbons was particularly evident in the Trinity Bay Study (Armstrong et al., 1979) and studies at coastal Louisiana sites (Boesch and Rabalais, 1989). Concentrations of naphthalenes in the sediment were enriched compared to effluent levels (21 mg/kg in the sediment versus 1.62 mg/liter in the effluent). Also, levels of naphthalenes were elevated in the immediate vicinity of the discharge with a subsurface concentration maximum in the sediment.

Neff et al. (1988) report little chemical contamination at their study sites that exceeded a 300 m radius. However, in Boesch and Rabalais (1989), hydrocarbon contamination at one study site (total alkanes, FFPI) at 800 m was about three times higher than at 1300 m; at another site, contamination (FFPI) at 600 m was 3.5-times that observed at 2,800 m. Thus, background was achieved at these sites somewhere between 600 m and 2,800 m or between 800 m and 1,300 m. Also at one of these sites, resolved saturates in one set of stations 1,100 m from the discharge were 16-fold those at 1,500 m and in another set of stations were 15-fold higher at 1,900 m than at 2,800 m. At these same sets of stations, total PAHs were 2.4-fold higher at

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Table 4-11. Comparison of Shallow Water and EPA Region 10 OOC Mud Discharge Model Runs

	Shallow Water Data Set	Region 10 OOC Data Set
Total Set Average		
Dilution at 100 m	898	1,077
Lower Half Average		
Dilution at 100 m	212	562

1,100 m than at 1,500 m and >4.5-fold higher at 1,900 m than at 2,800 m. These data suggest background levels may have been achieved at a distance anywhere between 600 m and 2,800 m.

The subsequent fate of petroleum hydrocarbons associated with sediments will depend on resuspending and transporting processes, desorption processes, and biological processes. Because produced waters provide a continuous input of light aromatic hydrocarbons over the life of a field (generally 10 to 30+ years), there is the potential for these chemicals to accumulate in sediments. This differs from oil spill situations wherein the chemicals are rapidly lost and the sediments generally exhibit a decline of lighter aromatics with time.

Concentrations of volatile liquid hydrocarbons discharged with produced water at the Buccaneer Field were reduced on the order of 10^{-4} to 10^{-5} within 50 m from the platform, but generally elevated levels were observed 3.5 km away. The Buccaneer Field platform is very much at the lower end of discharge volumes reported (600 bbl/day) for the EPA verification study (134 bbl/day-150,000 bbl/day; Middleditch, 1981).

Chemical processes important to the fate of produced water constituents generally are those that affect metal and petroleum hydrocarbon behavior in marine systems. Factors affecting metals have been described above under drilling fluids. The processes affecting petroleum hydrocarbons are briefly described here.

An important factor affecting the fate of hydrocarbons in produced water is volatilization. Produced water contains a high fraction of volatile compounds (e.g., benzene), which can be lost from the system over time. However, because produced water can be much more dense than seawater (salinities >150 ppt are not uncommon), discharge plumes sink rapidly. Thus, elevated levels of benzene in bottom water have been observed (Boesch and Rabalais, 1989). For compounds with higher molecular weights, a major chemical process involves biodegradation of compounds over time. Polynuclear aromatic hydrocarbons tend to be more resistant to such degradation and, thus, can persist in the environment (primarily in sediment) for extended periods.

4.3.1 Biological Transport Processes

Biological transport processes occur when an organism performs an activity with one or more of the following results:

- An element or compound is removed from the water column;
- A soluble element or compound is relocated within the water column;
- An insoluble form of an element or compound is made available to the water column; or
- An insoluble form of an element or compound is relocated.

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Biological transport processes include bioaccumulation in soft and hard tissues, biomagnification, ingestion and excretion in fecal pellets, and reworking of sediment to move material to deeper layers (bioturbation).

Ingestion and Excretion

Organisms remove material from suspension through ingestion of suspended particular matter and excretion of this material in fecal pellets. These larger pellets exhibit different transport characteristics than the original smaller particles. Houghton et al. (1981) notes that filter-feeding plankton and other organisms ingest fine suspended solids (1 μm to 50 μm) and excrete large fecal pellets (30 μm to 3,000 μm) with a settling velocity typical of coarse silt or fine sand grains. The study also notes that copepods are important in forming aggregate particles.

Zooplankton have been found to play a major role in transporting metals and petroleum hydrocarbons from the upper water levels to the sea bottom (Hall et al., 1978). The largest fraction of ingested metals moves through the animal with the unassimilated food and passes out with the fecal pellets in a more concentrated state (Fowler, 1982). Zooplankton fecal pellets have also been found to contain high concentrations of petroleum oil, especially those of barnacle larvae and copepods. Hall et al. (1978) calculates that a population of calanoid copepods grazing on an oil slick could transport three tons of oil per square kilometer per day to the bottom.

Bioaccumulation and Biomagnification

Studies assessing biomagnification of certain petroleum hydrocarbons are more limited than for other pollutants. The data available suggest that these contaminants are not subject to biomagnification. One reason for this observation is that the primary source of these compounds for organisms may be absorption from the water column rather than ingestion. Additionally, biological half-times of some petroleum hydrocarbons may be short, with many species purging themselves within a few days.

There is some evidence that hydrocarbons discharged with produced water are bioaccumulated by various marine organisms. In a central Gulf of Mexico study (Nulton et al., 1981a), analyses revealed the presence of low levels of alkylated benzenes, naphthalenes, alkylated naphthalenes, phenanthrene, alkylated three-ring aromatics, and pyrene in a variety of fish and epifauna. Isomer distributions of alkylated benzenes and naphthalenes were similar to those seen in crude oil.

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Middleditch (1980) analyzed hydrocarbons in tissues of organisms in the Buccaneer Field. During the first two years of the study, tissue from barnacles from the platform fouling community at depths approximately 3 m below the surface contained up to 4 ppm petroleum alkanes. Middleditch (1980), in studying the fouling community and associated pelagic fish, found that many species were contaminated with hydrocarbons discharged in produced water. Middleditch claims that biodegradation of petroleum hydrocarbons in the barnacles was apparently efficient. Analyses of the fouling mat on the platform revealed that most samples contained petroleum hydrocarbons, and concentrations were particularly high in those collected just below the air/sea surface.

Middleditch (1980) found petroleum hydrocarbons in 15 of 31 fish species examined around the Buccaneer Field platform. Analyses were focused on four species--crested blenny, sheepshead, spadefish, and red snapper. Virtually every specimen of crested blenny examined contained petroleum alkanes. In this species, the n-octadecane/phytane ratio was similar to that of produced water but the n-octadecane/pristane ratio is distorted by the presence of endogenous pristane of biogenic origin. The mean alkane concentration in this species was 6.8 ppm. This species feeds on the platform fouling community, and it was suggested that this food was the source of petroleum hydrocarbons to the fish.

Similar results were obtained with sheepshead, which also partially feed on the platform community. Petroleum alkanes were found in about half of the muscle samples and in about one quarter of the liver samples. The mean alkane concentration in these tissues were 4.6 and 6.1 ppm, respectively.

Spadefish exhibited lower concentrations of alkanes in muscle and liver (0.6 and 2.0 ppm), and this species does not utilize the platform fouling community as a food source to the same extent as the two previously described species. Lower levels of alkanes were also observed in red snapper (1.3 ppm in muscle, and 1.1 ppm in livers).

With one exception, most shrimp analyzed by Middleditch did not contain alkanes. This probably reflects the highly migratory behavior of these animals. Similarly, the petroleum hydrocarbons were not found in white squid.

Middleditch also examined nine benthic organisms for petroleum hydrocarbons. Yellow corals (*Alcyonarians*) contained alkanes, but Middleditch suggested these could be of biogenic origin. Various hydrocarbon profiles were observed in species. Few of the specimens of winged oyster (*Pteria colymbus*) contained petroleum alkanes while they did contain methylnaphthalenes and benzo[a]pyrene.

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4.4   DISCHARGE MODELING - PRODUCED WATER

4.2.1 UDKHDEN Model

To assess the dilution of produced water discharges, a modification of EPA's ocean outfall model UDKHDEN was used (U.S. EPA, Region 10, 1985). The standard model, which was designed for sewage effluents, was adapted to accommodate a negatively buoyant plume because of the density of produced water discharges, which can be up to four times as saline as seawater. Entrainment is determined empirically as a function of plume size, excess velocity, local Froude number, and ambient velocity. Governing equations are solved and evaluated using a power function approximation of Gaussian profiles.

UDKHDEN requires input of the rate of volumetric flow (m^3/sec); the number, depth, and diameter of discharge ports; and the angle of discharge relative to horizontal and vertical currents. UDKHDEN also requires ambient current velocity and density (or temperature and salinity) as a function of depth, as input. A maximum of 20 stratifications can be represented. UDKHDEN provides data on plume trajectory, size, average dilution, center line dilution, time density difference, and trapping level.

In general, the input data requirements related to waste streams are adequately addressed with existing information. A possible exception includes the densities of produced waters with salinities greater than 40 ppt, which is the reasonable limit of the usual algorithms used to estimate density based on temperature and salinity data inputs. However, produced water can attain salinity in excess of 150 ppt, and the densities and salinities of only a very limited number of produced water samples have been analyzed. Operational data are generally adequate to fulfill the data input needs for the model. However, the existing data on port diameter, number of ports, discharge depth, and volumes of produced water discharges are very limited. These discharges data should be more extensively characterized.

4.4.2 Derivation of Dilution Estimates

Input data for ambient conditions for the model predictions used in the OCS general permit are generally based on the Buccaneer oil and gas field study conducted by Middleditch (1981). Ambient conditions were characterized for water depths of 6.5-40.5 m. Salinity, temperature, and current gradients were determined from the study and linearly extrapolated for the greater depths.

The salinity of the effluent was determined from a database created from permit submissions for coastal facilities located in Louisiana (*Avanti* Corporation, 1991). A value of 42.5 ppt was used, which is two

standard deviations below the mean value for coastal facilities. The discharge scenarios include a range of discharge rates and discharge pipe, or port, diameters. The discharge rates used in the model range from 500-250,000 bpd and the pipe diameters used range from 2-36 inches.

The output from the model supplies plume dimensions (height and width), placement of the plume in the water column, distance from the outfall, time, and dilutions available at set distances from the outfall. To determine the number of dilutions available at 100 m from the outfall for the projection of pollutant concentrations at the edge of the mixing zone, the plume dimensions at the point where the plume reached equilibrium height were entered as input into a simplistic screening equation for discharged-induced mixing (U.S. EPA, 1985):

$$S = 0.3 \; \frac{x}{d}$$

where:

S = Flux-averaged dilution at 100 m
x = Distance from source (100 m - distance at which plume reached initial mixing)
d = Diameter of outfall (plume width at equilibrium height)

4.4.3 Model Results

The results of the model runs are presented in Table 4-12. The results are give as the percent of the whole effluent that would be present in the water column at 100 m from the outfall pipe. This is calculated as

100/number of dilutions available for the specified pipe diameter and discharge rate x 100%.

The model could not successfully predict dilution of low volume discharges from larger pipe diameters due to low Froude numbers. At low discharge rates the discharge volume was insufficient to fill the pipe, and therefore, there was insufficient trajectory to model the plume.

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Table 4-12. Percent Effluent at Edge of 100-meter Mixing Zone

Discharge Rate (bbl/day)	Pipe Diameter (inches)						
	2	4	6	8	10	12	24
500	0.03	-	-	-	-	-	-
1,000	0.06	-	-	-	-	-	-
2,000	0.09	0.11	-	-	-	-	-
3,000	0.14	0.15	-	-	-	-	-
4,000	0.16	0.18	0.22	-	-	-	-
5,000	0.18	0.22	0.26	-	-	-	-
6,000	0.19	0.25	0.29	-	-	-	-
7,000	0.20	0.28	0.32	-	-	-	-
8,000	0.20	0.30	0.36	-	-	-	-
9,000	0.21	0.31	0.38	-	-	-	-
10,000	0.22	0.34	0.42	-	-	-	-
15,000	0.23	0.40	0.53	0.91	0.43	-	-
20,000	0.23	0.43	0.50	0.59	0.56	-	-
25,000	0.23	0.43	0.56	0.67	0.63	0.59	-
30,000	0.23	0.43	0.59	0.71	0.71	0.67	-
40,000	0.23	0.43	0.63	0.83	0.83	0.83	-
50,000	0.23	0.45	0.67	0.83	0.91	0.91	-
75,000	0.23	0.48	0.67	0.91	1.0	1.1	-
100,000	0.23	0.48	0.67	0.91	1.1	1.2	-
150,000	0.23	0.48	0.71	0.91	1.1	1.3	2.5
200,000	0.23	0.47	0.71	0.91	1.1	1.3	2.5
250,000	0.23	0.48	0.71	0.91	1.1	1.4	2.5

5. TOXICITY AND BIOACCUMULATION

5.1 OVERVIEW

The release of drilling fluids and cuttings and produced water from oil and gas platforms is of interest because of the magnitude and potential toxicity of the discharges. Additionally, studies have shown that some marine biota bioaccumulate components of the discharges. Many data are available on the toxicity of drilling fluids to marine species; however, much less is known of the ecological implications of these toxicities and the extent of bioaccumulation of discharged drilling fluids. Only limited information is available on the acute and chronic effects of produced water. The following is a brief summary of pertinent information on these subjects. In reviewing the data contained in this section, it is important to note that the proposed permit limits the toxicity of drilling fluids (30,000 ppm of the suspended particulate phase), prohibits the discharge of mud containing diesel, and limits the cadmium and mercury content of drilling mud so that only the less contaminated sources of barite can be used to formulate muds discharged from this operation. In addition, produced water discharges must be analyzed to determine their toxicity and to assess compliance with water quality-based permitting strategies.

5.2 TOXICITY OF DRILLING FLUIDS

Toxicity testing data are often used to estimate the potential for environmental damage, even though uncertainty arises from the extrapolation of single species tests to ecological assessments. The interest in potential environmental effects of drilling has prompted researchers to conduct tests with various drilling muds, drilling mud fractions, and a wide variety of test organisms. Used muds appear to exhibit higher toxicity than new muds, although this observation remains controversial. Neff et al. (1980) cite decomposition of organic materials during the drilling process (high temperature, pressure, and alkalinity characteristics of downhole drilling conditions) as the probable cause of increased toxicity of used drilling fluids. The presence of diesel oil in used drilling mud has also been shown to contribute to increased toxicity (Conklin et al., 1983; Duke and Parrish, 1984).

There are several "fractions" or phases of drilling fluids that have been used in toxicity testing, including:

- Suspended Particulate Phase (SPP). One part by volume of drilling fluid is added to nine parts seawater. The drilling fluid-seawater slurry is well mixed and the suspension is allowed to settle for one hour before the supernatant SPP is decanted off. The SPP is mixed for five minutes and then used immediately in bioassays. Testing protocol currently employed by EPA specifies testing of the SPP.

- Layered Solid Phase (LSP). A known volume of drilling fluid is layered over the bottom of the test vessel or added to seawater in the vessel. Although little or no mixing of the slurry occurs during the test, the water column contains a residual of very fine particulates which do not settle out of solution.

- Suspended Solids Phase (SSP). Known volumes of drilling fluids are added to seawater and the mixture is kept in suspension by aeration or mechanical means.

- Mud Aqueous Fraction (MAF). One part by volume of drilling fluid is added to either four or nine parts seawater. The mixture is stirred thoroughly and then allowed to settle for 20-24 hours. The resulting supernatant MAF is siphoned off for immediate use in bioassays. The MAF is similar to the SPP but has a longer settling time, so the concentration of particulates in the supernatant is lower.

- Filtered Mud Aqueous Fraction (FMAF). The mud aqueous fraction of whole drilling fluid is centrifuged and/or passed through a 0.45 um filter and the resulting solution is the filtered mud aqueous fraction.

5.2.1 Acute Toxicity

Acute toxicity tests of whole drilling fluids have generally produced low toxicity. Petrazzuolo (1983) summarized the results of 415 such tests of 68 muds in 70 species and found 1 to 2 percent had LC50's ranging from 100 to 999 ppm, 6 percent had LC50's ranging from 1,000 to 9,999 ppm, 46 percent had LC50's ranging from 10,000 to 99,999 ppm, and 44 percent had LC50's of greater than 100,000 ppm (Table 5-1). For purposes of comparison, almost all acute toxicities to marine organisms for EPA's 129 priority pollutants fall into the range from 0.007 ppm to 270 ppm (U.S. EPA, 1980a-i).

Test results also indicate that whole drilling fluid is more toxic than the aqueous or particulate fractions (Table 5-2). These data show whole fluid toxicity ranging from one to five times that of the aqueous fraction, and 1.3 times the toxicity of the particulate fraction. Acute toxicity tests for used drilling fluids and drilling fluid components are shown in Table 5-3. Criterion values for drilling fluid fractions in the table are converted to whole fluid equivalents. For example, the MAF is prepared by mixing one part drilling mud with nine parts seawater, so an LC50 value derived from 100 percent MAF is actually the supernatant from a 10 percent drilling fluid mixture and is therefore expressed as 100,000 ppm (10 percent whole fluid equivalent).

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Table 5-1. Summary Table of the Acute Lethal Toxicity of Drilling Fluid

	Number of species tested	Number of fluids tested	Number of tests	Not determinable	Number of 96-hr LC50 values (ppm)[a]				
					< 100	100-999	1,000-9999	10,000-99,000	>100,000
Phytoplankton	1	9	12	5	0	0	7	0	0
Invertebrates									
Copepods	1	9	11	1	0	3	5	2	0
Isopods	2	4	6	0	0	0	0	1	5
Amphipods	4	11	22	0	0	0	0	7	15
Gastropods	5	5	10	0	0	0	0	7	15
Decapods								2	8
Shrimp	9	23	66	0	0	6(1)[b]	5	36	19
Crab	8	18	32	1	0	0	3	17	11
Lobster	1	2	7	0	0	0	1	3	3
Bivalves	11	22	59	19[d]	0	0	1	19	20
Enchinoderms	2	2	4	0	0	0	0	1	3
Mysids	4	17	64	2(1)[d]	0	0	1	29	32
Annelids	7	14	34	3[d]	0	0	0	12	19
Finfish	15	24	80	0	0	0	2	50	36
TOTALS	40	40[c]	303	31(23)[d]	0	4-9	25	179	171
Percentages as a fraction of the total number of tests	70	68	415 / 392[e]	2%	0%	2.4%	6% (1%)[b]	46%	44%
Average percentage in a category for each group of animals				5.3%	0%	2.8% (2.1%)[b]	9.4%	33%	50%

Source: Adapted from Petrazzuolo (1983).

[a] Placement in classes according to LC50 value. Lowest boundary of range if LC50 expressed as a range. Cited values if given as ">" or "<". There were 199 such LC50 values; 95 were 100,000 ppm; 20 were <3,200 ppm.

[b] These include tests conducted on drilling fluids obtained from Mobile Bay, Alabama, and which may not be representative of drilling fluids used and discharged on the OCS. The value in parentheses is the result of not including those drilling fluids.

[c] The fluids used in Gerber et al, 1980, Neff et al, 1980, and Carr et al, 1980 were all supplied by API. Their characteristics were very similar and they may have been subsamples of the same fluids. If so, the total number of fluids tested would be 35.

[d] Data not available.

[e] Number of tests with actual data.

Table 5-2. Comparison of Whole Fluid Toxicity and Aqueous and Particulate
Fraction Toxicity for Some Organisms

Organism	Whole fluid vs. aqueous fraction	Whole fluid vs. particulate fraction
Gammarus (amphipod)	> 1.4 to 3.6:1	
Thais (gastropod)	> 1.2:1	
Crangon (shrimp)	> 1.1 to 1.4:1	
Carcinus (crab)	> 1.1 to 1.5:1	
Homarus (lobster)	> 3.5 to 5.3:1	
Strongylocentrotus (sea urchin)	> 2:1	
Coregonus (whitefish)	< 1.7:1	
Neomysis (shrimp)		1.3:1

Source: Petrazzuolo, 1981

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms[*]

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
		USED DRILLING FLUIDS		
ALGA				
Skeletonema costatum	Imco LDLS/SW	1,325-4,700 (96-h EC50)	4	1
	Imco Lime/SW	1,375 (96-h EC50)	4	1
	Imco non-dispersed/SW	5,700 (96-h EC50)	4	1
	Lightly treated LS/SW-FW	3,700 (96-h EC50)	4	2
COPEPODS				
Acartia tonsa	Imco LDLS/SW	5,300-9,300	4	1
	Imco Lime/SW	5,600	4	1
	Imco non-dispersed/SW	66,500	5	1
	Lightly treated LS/SW-FW	10,000	5	2
	FCLS/FW	100-230	3	2
	Saltwater Gel	100	3	2
ISOPODS				
Gnorimosphaeroma oregonsis	FCLS/FW	70,000	5-6	3
Saduria entomon	XC-Polymer/Unical	314,000-500,000	6	4
	CMC-Resinex Tannathin-Gel	530,000-600,000	6	4
AMPHIPODS				
Anisogammarus confervicolus	FCLS/FW	10,000-50,000	5	3
	FCLS/FW	10,000-200,000 (48-h LC50)	5-6	3
Onisimus sp./*Boeckisima* sp.	XC-Polymer/Unical	200,000-436,000	6	4
Gammarus locusta	Spud mud	100,000	6	5
	MDLS	74,000-90,000	5	5
	MDLS (MAF)	100,000	6	5
	HDLS	28,000-88,000	5	5
	HDLS (MAF)	100,000	6	5

(continued)

Source: Adapted from Petrazzuolo, 1981.
[*] 96-hour LC50 unless otherwise noted; footnotes at end of table.

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Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
GASTROPODS				
Nautica clausa, Neptuna sp., & *Buccinum* sp. *Littorina littorea* *Thais lapillis*	CMC-Resinex Tannathin-Gel	600,000-700,000	6	4
	LDLS (MAF)	100,000	6	5
	LDLS	83,000	5	5
	LDLS (MAF)	100,000	6	5
	LDLS (suspended WM)	15,000	5	5
	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5
DECAPODS-SHRIMP				
Artemia salina *Pandalus hypsinotus*	FCLS/FW	100,000 (48-h LC50)	6	3
	FCLS/FW	32,000-150,000	5-6	3
Crangon septemspinosa	Spud mud (MAF)	50,000-100,000 (48-h LC50)	5	3
	Seawater LS (MAF)	100,000	6	5
	LDLS	100,000	6	5
	LDLS (suspended WM)	71,000	5	5
	LDLS (MAF)	15,000	5	5
	MDLS	98,000-100,000	5	5
	MDLS (suspended WM)	82,000	5	5
	MDLS (MAF)	15,000	5	5
	MDLS (FMAF)	17,000	5	5
	HDLS	19,000	5	5
	HDLS (suspended WM)	92,000	5	5
	HDLS (MAF)	15,000	5	5
	HDLS (FMAF)	100,000	6	5
Pandalus borealis	HDLS (MAF)	65,000	6	5
Stage I larvae	HDLS (FMAF)	55,000	5	5
Palaemonetes pugio	Spud Mud (MAF)	100,000	6	6
Stage I zoeae	Seawater-chrome LS (MAF)	27,500	5	6

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Adults	MDLS (MAF)	35,000	5	6
	HDLS (MAF)	18,000	5	6
	HDLS (SPP)	11,800	5	6
	Spud Mud (MAF)	100,000	6	6
	Seawater-chrome LS (MAF)	92,400	5	6
	MDLS (MAF)	91,000	5	6
	HDLS (MAF)	100,000	6	6
	Lightly treated LS	201	3	11
Stage III zoeae	HDLS (SPP)	11,700-13,200	5	6
Late premolt stage	Mobile Bay fluid	318-863	3	7
D₂ - D₄	Mobile Bay fluid	360-14,560	3-5	9
Palaemonetes pugio				
larvae	Seawater LS	1,706-28,750	4-5	11
	Lightly treated LS	142	3	11
	Freshwater LS	4,276-4,509	4	11
	Lime	658	3	11
	FW/SW-LS	3,570	4	11
	Non-dispersed	100,000	6	11
	LTLS	35,420	5	11
	Seawater-K-polymer	2,557	4	11
Penaeus aztecus				
juvenile	Seawater-chrome LS (MAF)	41,500	5	6
Orchestia traskiana	MDLS (MAF)	16,000	5	6
	Seawater-polymer	230,000	6	8
	Pelly gel Chemical XC	80,000	5	8
	KCl-XC-Polymer	14,000	5	8
	Weighted shell polymer	34,000	5	8
	Gel-SX-polymer	420,000-500,000	6	8
	Imnak gel-XC-polymer	560,000	6	8
DECAPODS-CRABS				
Carcinus maenus	LDLS	89,100	5	5
	LDLS (suspended WM)	15,000	5	5

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description [a]	Criterion Value (ppm)	Toxicity Rating [b]	Reference [c]
Clibanarius vittatus	LDLS (MAF)	100,000	6	5
	MDLS	68,000-100,000	5-6	5
	MDLS (suspended WM)	15,000	5	5
	MDLS (MAF)	100,000	6	5
	HDLS (MAF)	100,000	6	5
	Seawater-chrome LS (MAF)	28,700	5	6
	MDLS (MAF)	34,500	5	6
	HDLS (MAF)	65,600	5	6
Hemigrapsus nudus	Seawater polymer	530,000	6	8
	Shell Kipnik-KCL polymer	53,000	5	8
	Pelly gell chemical XC	560,000	6	8
	KCl-XC-polymer	78,000	5	8
	Weighted shell polymer	62,000	5	8
	Pelly weighted gel-XC-polymer	560,000	6	8
	Imnak gel-XC-polymer	560,000	6	8
DECAPODS-LOBSTER				
Homarus americanus				
Stage V larvae	LDLS (MAF)	5,000	5	5
	MDLS	100,000	6	5
	MDLS (MAF)	29,000	5	5
Adult	LDLS	19,000-25,000	5	5
Larvae	LDLS (MAF)	100,000	6	5
	Mobile Bay/Jay fluids 73.8-500 ppm		2-3	10
BIVALVES				
Modiolus modiolus	FCLS/FW	30,000	5	3
Mytilus edulis		30,000 (14 day LC50)	5	3
	Spud mud (MAF)	100,000	6	5
	Seawater LS (MAF)	100,000	6	5
	MDLS (MAF)	100,000	6	5
	MDLS (suspended WM)	15,000	5	5
	HDLS (MAF)	100,000	6	5
	HDLS (suspended WM)	15,000	5	5

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Macoma balthica				
	LDLS	100,000	6	5
	LDLS (MAF)	100,000	6	5
	LDLS (suspended WM)	15,000	5	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5
	HDLS (FMAF)	100,000	6	5
Placopecten magellanicus				
	LDLS	49,000	5	5
	MDLS	3,200	4	5
Crassostrea gigas				
	Spud mud (SPP)	100,000	6	6
	MDLS (SPP)	50,000-53,000	5	6
	HDLS (SPP)	73,000-74,000	5	6
Donax variabilis texasiana				
	Spud mud (SPP)	100,000	6	6
	Seawater-chrome LS (SPP)	53,700	5	6
	MDLS (SPP)	29,000	5	6
	HDLS (SPP)	56,000	5	6
Mya arenaria				
	Seawater polymer	320,000	6	8
	Kipnik-KC1 polymer 42,000		5	8
	Polly gel chemical XC 560,000		6	8
	KC1-XC-polymer	56,000	5	8
	Weighted shell polymer	10,000	5	8
	Weighted gel XC-polymer	560,000	6	8
	Weighted KC1-XC-polymer	560,000	6	8
	Imnak gel-XC-polymer	560,000	6	8
Mercenaria mercenaria				
Larvae	Seawater LS (LP)	87-3,000	2-4	11
	Seawater LS (SPP)	117-3,000	3-4	11
	LTLS (LP)	719-3,000	3-4	11
	LTLS (SPP)	122-2,889	3-4	11
	FWLS (LP)	319-330	3	11
	FWLS (SPP)	158-338	3	11
	FW/SW LS (LP)	380	3	11
	FW/SW LS (SPP)	82	2	11
	Lime (LP)	682	3	11
	Lime (SPP)	64	2	11

(continued)

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
	Low solids non-dispersed (LP)	3,000	4	11
	Low-solids non-dispersed (SPP)	3,000	4	11
	Potassium polymer (LP)	269	3	11
	Potassium polymer (SPP)	220	3	11
ECHINODERMS				
Strongylocentrotus droebachiensis	LDLS	55,000	5	5
	LDLS (MAF)	100,000	6	5
	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
MYSIDS				
Neomysis integer	FCLS/FW	10,000-200,000 (48-h LC50)	5-6	3
		10,000-125,000	5-6	3
Mysis sp.	CMC-Gel	142,000-349,000	6	4
	CMC-Gel-Resinex	58,000-93,000	5	4
	XC-polymer (supernatant)	250,000	6	4
	XC-polymer	50,000-170,000	5-6	4
Mysidopsis almyra	Spud mud (MAF)	100,000	6	6
	Seawater-chrome LS (MAF)	27,000	5	6
	MDLS (MAF)	12,800-13,000	5	6
	HDLS (MAF)	16,000-32,500	5	6
	MDLS (SPP)	32,000	5	12
	MDLS (MAF)	26,800-66,300	5	12
	MDLS (MAF) (static test)	72,100-113,000	5-6	12
	Reference mud (MAF) (static test)	100,000	6	12

(continued)

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Mysidopsis bahia	Seawater LS	429-1,557	3-4	11
	Seawater LS (LP)	150,000	6	11
	Seawater LS (SPP)	15,123-19,825	5	11
	Seawater LS (SP)	50,000	5	11
	LTLS	14-1,958	2-4	11
	LTLS (LP)	150,000	6	11
	LTLS (SPP)	1,641-50,000	3-5	11
	LTLS (SP)	1,246-2,437	3	11
	FWLS	301-1,500	3-4	11
	FWLS (LP)	97,238-121,476	5-6	11
	FWLS (SPP)	14,068-29,265	5	11
	Lime	87-98	2	11
	Lime (SPP)	650-791	3	11
	Lime (SP)	8,213-1,369,393	4-6	11
	FW/SW-LS	115-379	3	11
	FW/SW-LS (LP)	150,000	6	11
	FW/SW-LS (SPP)	11,380-38,362	5	11
	FW/SW-LS (SP)	50,000	5	11
	Low-solids non-dispersed	1,500	4	11
	Low-solids non-dispersed (LP)	150,000	6	11
	Low-solids non-dispersed (SPP)	50,000	5	11
	Low-solids non-dispersed (SP)	50,000	5	11
	Potassium polymer	1,500	4	11
	Potassium polymer (LP)	150,000	6	11
	Potassium polymer (SPP)	26,025-28,070	5	11
POLYCHAETES				
Melaenis loveni	CMC-Resinex-Tannathin	600,000	6	4
	CMC-Resinex-Tannathin-Gel	700,000	6	4

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Nereis virens	Spud mud (MAF)	100,000	6	5
	Seawater-LS (MAF)	100,000	6	5
	LDLS	100,000	6	5
	LDLS (MAF)	100,000	6	5
	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5
Ophryotrocha labronica	Spud mud (MAF)	100,000	6	6
	Seawater-chrome LS (MAF)	100,000	6	6
	MDLS (MAF)	60,000	5	6
	HDLS (MAF)	100,000	5	6
Neveis vexillosa	Seawater polymer	220,000	6	8
	Kipnik-KC1 polymer	37,000	5	8
	Gel chemical XC	560,000	6	8
	KC1-XC-polymer	41,000	5	8
	Weighted shell polymer	23,000	5	8
	Weighted gel XC-polymer	320,000-560,000	6	8
	Imnak gel-XC-polymer	200,000	6	8
TELEOST FISH				
Menidia menidia	Imco LDLS/SW	56,500-175,000	5-6	1
	Imco Lime	43,000-53,000	5	1
	Imco non-dispersed	345,000-385,000	6	1
	Saltwater gel	100,000	6	2
	LDLS-SW/FW	48,500	5	2
	FCLS	100,000	6	2
Oncorhynchus gorbuscha	FCLS/FW	3,000-29,000	4-5	3
Leptocuttus armatus	FCLS/FW	100,000-200,000	6	3
Myoxocephalus quadricomis	CMC-Gel	120,000	6	4
	CMC-Gel-Resinex	50,000-70,000	5	4
	XC-Polymer	50,000-215,000	5-6	4
	XC-Polymer (supernatant)	250,000	6	4

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Coregonus nasus	Lignosulfonate	350,000	6	4
	CMC-Gel	200,000	6	4
	XC-Polymer	57,000-370,000	5-6	4
	XC-Polymer (supernatant)	100,000-250,000	6	4
Elegonus naraga	Lignosulfonate	0-100,000	6	4
Boreogadus saida	CMC-Gel	170,000-300,000	6	4
	XC-Polymer	250,000	6	4
Coregonus autumnalis	Lignosulfonate	200,000-250,000	6	4
Fundulus heteroclitus	Lignosulfonate	85,000-1,000,000	6	4
	Spud mud (MAF)	100,000	6	5
	Seawater-LS (MAF)	100,000	6	5
	MDLS (suspended whole mud)	15,000	5	5
	MDLS (MAF)	100,000	6	5
	HDLS (suspended whole mud)	15,000	5	5
	HDLS (MAF)	100,000	6	5
Salmo gairdneri (juvenile)	Kipnik-KC1 polymer 24,000-42,000			
	Seawater polymer	130,000	5	8
	KC1-XC polymer	34,000	6	8
	Weighted shell polymer	16,000	5	8
	Pelly gel chemical-XC 42,000		5	8
	Weighted gel XC-polymer	18,000-48,000	5	8
	Imnak-Gel XC-polymer	42,000	5	8
Oncorhynchus kisutch (juvenile)	Kipnik-KC1 polymer 29,000		5	8
	Seawater polymer	130,000	5	8
	KC1-XC polymer	20,000-23,000	5	8
	Weighted shell polymer	4,000-15,000	5	8
	Pelly Gel chemical-XC	28,000-130,000	4-5	8
	Weighted gel XC-polymer	24,000-190,000	5-6	8
	Imnak-Gel XC-polymer	23,000-30,000	5-6	8
O. keta (juvenile)	Kipnik-KC1 polymer 24,000		5	8
O. gorbuscha (juvenile)	Kipnik-KC1 polymer 41,000		5	8

(continued)

Table 5-3. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (continued)

DRILLING FLUID COMPONENTS

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Skeletonema costatum	Barite	385-1,650	3-4	2
	Aquagel	9,600	4	3
Arcartia tonsa	Barite	590	3	2
	Aquagel	22,000	5	2
Pandalus hypsinotus	Barite	100,000	6	3
	Aquagel	100,000	6	3
Molliensias latipinna	Barite	100,000	6	13
	Calcite	100,000	6	13
	Siderite	100,000	6	13
	Chrome lignosulfonate	7,800-12,200	4-5	14
	Quebracho	135-158	3	14
	Lignite	15,500-24,500	5	14
	Sodium acid pyrophosphate	1,200-7,100	4	14
Penaeus setiferus	Hemlock bark extract	265	3	15
	Polyacrylate	3,500	4	15
	CaCO₃ workover additive	1,925	4	15
	Chrome-treated lignosulfonate	465	3	15
	Lead-treated lignosulfonate	2,100	4	15

Table footnotes and references appear on following page.

Table 5-3. Footnotes and References

a Drilling fluids abbreviations (test fractions in parenthesis):

WM = Whole mud
MAF = Mud aqueous fraction
FMAF = Filtered mud aqueous fraction
SPP = Suspended particulate phase
SP = Solid phase
LP = Liquid phase

SW = Saltwater dispersed
FW = Freshwater dispersed
LS = Lignosulfonate
LDLS = Low-density lignosulfonate
MDLS = Medium-density lignosulfonate
HDLS = High-density lignosulfonate
LTLS = Lightly-treated lignosulfonate
FCLS = Ferrochrome lignosulfonate

b Toxicity ratings as per Hocutt & Stauffer, 1980.
   1. Very toxic (1 ppm)
   2. Toxic (1-100 ppm)
   3. Moderately toxic (100-1,000 ppm)
   4. Slightly toxic (1,000-10,000 ppm)
   5. Practically non-toxic (10,000-100,000 ppm)
   6. Non-toxic (100,000 ppm)

c References:
   1. Imco, 1977.
   2. Shell Oil Co., 1976, as cited in Petrazzuolo, 1981.
   3. Atlantic Richfield, 1978, as cited in Petrazzuolo, 1981.
   4. Tornberg et al., 1980.
   5. Gerber et al., 1980.
   6. Neff et al., 1980.
   7. Conklin et al., 1980.
   8. Environmental Protection Service, 1976, as cited in Petrazzuolo, 1981.
   9. Conklin et al., 1983.
   10. Capuzzo and Derby, 1982.
   11. Duke et al., 1983 (or Rao, 1983).
   12. Carr et al., 1980.
   13. Grantham and Sloan, 1975, as cited in Petrazzuolo, 1981.
   14. Hollingsworth and Lockhart, 1975.
   15. Chesser and McKenzie, 1975.

Petrazzuolo (1981) used a semi-quantitative procedure to rank organisms in terms of sensitivity to drilling fluids, based on laboratory tests. The results ranked groups of organisms as follows, in order of decreasing sensitivity: copepods and other plankton; shrimp; lobster; mysids and finfish; bivalves; crab; amphipods; echinoderms; gastropods and annelids; and isopods. This ranking is admittedly biased because it is limited by the actual bioassay test results that have been published, and not based on theoretical considerations. For example, if more tests, more toxic drilling fluids, and more sensitive life stages have been tested on certain types of organisms, they would appear to be more sensitive in the rankings. These shortcomings notwithstanding, the ranking is a reasonable general indicator of the relative sensitivity of organisms to drilling fluids.

Toxicity tests also highlight the toxicity variations that occur during a given organism's life cycle. Larval stage organisms are generally more sensitive than adult stages, and animals are more sensitive while molting than during intermolt stages. These variations affect the potential for impact associated with offshore operations. Drilling fluids discharged into an area occupied by an adult community will presumably cause less impact than if the area were occupied by juvenile communities or serves as a breeding ground. Many organisms, including several commercially important species, have breeding or nursery grounds in estuaries or salt marshes.

Toxicity tests with larvae of the grass shrimp (*Palaemonetes intermedius*, Table 5-4) indicated that they are not as sensitive to whole muds as the mysids. Average 96-hour LC50 values for whole muds ranged from 142 to 100,000 ppm. *Mercenaria mercenaria* one-hour larvae showed a lack of development (48-hour EC50) at relatively low concentrations of the liquid and suspended solids phases of the muds (Table 5-5). Concentrations as low as 87 and 64 ppm (respectively) halted larval development. Similarly, embryogenesis of *Fundulus* and echinoderms was affected by drilling fluid exposure. "Safe" levels (defined as a concentration of 10 percent of that having an adverse effect on the most sensitive assay system) ranged from one to 100 ppm. A study of sublethal effects of drilling mud on corals (*Acropora cervicornis*) indicated a decrease in the calcification rate and changes in amino acids at concentrations of 25 ppm.

All of the muds tested in the used drilling mud study (Duke and Parrish, 1984) were found to contain some No. 2 fuel (diesel) oil. Surrogate "diesel" oil content ranged from 0.10 to 9.43 mg/g in the whole mud. Spearman Rank Order Correlation of the relationship between toxicity and fuel oil content showed a significant correlation between these factors in all tests. In all cases, the drilling fluids with higher diesel oil contents were more toxic to the organisms tested. A higher correlation was found with "diesel" (equivalent to AP1 #2 fuel oil) content than with either aromatic or aliphatic content. Toxicity also correlated better with organics in the suspended particulate phase than with organics in the whole mud, except for aromatics.

Table 5-4. Drilling Fluid Toxicity to Grass Shrimp (*Palaemonetes intermedius*) Larvae[a]

Mud	Type	96-h LC50 (95% CL)
MIB	Seawater Lignosulfonate	28,750 ppm (26,332-31,274)
AN31	Seawater Lignosulfonate	2,390 ppm (1,896-2,862)
SV76	Seawater Lignosulfonate	1,706 ppm (1,519-1,922)
P1	Lightly Treated Lignosulfonate	142 ppm (133-153)
P2	Freshwater Lignosulfonate	4,276 ppm (2,916-6,085)
P3	Lime	658 ppm (588-742)
P4	Freshwater Lignosulfonate	4,509 ppm (4,032-5,022)
P5	Freshwater/Seawater Lignosulfonate	3,570 ppm (3,272-3,854)
P6	Low Solids Nondispersed	100,000 ppm ---
P7	Lightly Treated Lignosulfonate	35,420 ppm (32,564-38,877)
P8	Seawater/Potassium/Polymer	2,577 ppm (2,231-2,794)
NBS Reference		17,917 ppm (15,816-20,322)

Source: Adapted from Duke and Parrish (1984).

[a] All tests conducted at 20 ppt salinity and $20 \pm 2°C$ with Day-1 larvae.

Table 5-5. Results of Continuous Exposure (48 hr) of 1-hr Old Fertilized Eggs of Hard Clams (*Mercenaria mercenaria*) to Liquid and Suspended Particulate Phases of Various Drilling Fluids

Drilling Fluid	Liquid Phase EC50 (μl/l)[a]	Control % "D" Stage	Suspended Particulate EC50 (μl/l)[a]	Control % "D" Stage
AN31	2,427 (2,390-2,463)	88	1,771 (1,710-1,831)	93
MIB	>3,000	95	>3,000	95
SV76	85 (81-88)	88	117 (115-119)	93
P1	712 (690-734)	97	122 (89-151)	99
P2	318 (308-328)	97	156 (149-162)	99
P3	683 (665-702)	98	64 (32-96)	99
P4	334 (324-345)	98	347 (330-364)	99
P5	385 (371-399)	98	382 (370-395)	99
P6	>3,000	97	>3,000	93
P7	>3,000	97	2,799 (2,667-2,899)	93
P8	269 (257-280)	93	212 (200-223)	93

Source: NEA (1984) in Duke and Parrish (1984).

[a] EC50 and 95% confidence limits. The percentage of each test control (n = 625 125 eggs) that developed into normal straight-hinge or "D" stage larvae and the EC50 is given

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Toxicity	Correlation Coefficient		
	Aromatic	Aliphatic	"Diesel"
Whole Mud	-0.79	-0.77	-0.81
Suspended Particulate Phase	-0.77	-0.89	-0.96

Since all of the muds contained some diesel oil, and the oil is clearly a factor in toxicity, then addition of diesel oil is a likely contributor to the increased toxicity of used versus unused drilling fluids.

Other studies further implicate diesel and mineral oil in the toxicity of certain drilling fluids. In these studies, the toxicity of drilling fluids with and without added diesel or mineral oil were compared (Table 5-6). The drilling fluids tested included "used" fluids as well as a National Bureau of Standards (NBS) reference fluid which contained no measurable amount of diesel. In each case, the addition of diesel or mineral oil increased the toxicity of the drilling fluids.

Conklin et al. (1983) also found a significant relationship between the toxicity of drilling fluids and diesel oil content. Their study was designed to assess the roles of chromium and petroleum hydrocarbons in the total toxicity of whole mud samples from Mobile Bay to adult grass shrimp (*Palaemonetes pugio*). The range of 96-hour LC50 values was from 360 to 14,560 ppm. The correlation between chromium concentration of the mud and the LC50 value was not significant; however, the correlation between diesel oil concentration and the LC50 value was significant. As the concentration of diesel oil in the muds increased, there was a general increase in the toxicity values. Similar toxicity tests using juvenile sheepshead minnows (*Cyprinodon variegatus*) showed higher LC50 levels but no significant correlation between either chromium or diesel oil content and toxicity.

5.2.2 Chronic Toxicity

Stress Tests on Corals

There has been considerable investigation regarding the effects of whole drilling fluids on corals, due to their sensitivity, ecological interest, and presence in the Texas Flower Garden Banks area. Respiration, excretion, mucous production, degree of polyp expansion, and clearing rates for materials deposited on the surface are all useful parameters for indicating stress.

Laboratory experiments using the corals *Montastrea* and *Diplora* showed essentially unchanged clearing rates after applications of calcium carbonate, barite, and bentonite. However, exposure to a used drilling

Table 5-6. Toxicity of API #2 Fuel Oil, Mineral Oil, and Oil-Contaminated
Drilling Fluids to Grass Shrimp (*Palaemonetes intermedius*) Larvae

Materials Tested	Oil Added (g/l)	Total Oil Content (g/l)	96-h LC50 & 95% CL[a] (ppm; μl/l)
API #2 fuel oil[b]	---	---	1.4 (1.3-1.6)
Mineral Oil[c]	---	---	11.1 (9.8-12.5)
P7 mud	None	0.68	35,400 (32,564-38,877)
P7 mud + API #2 fuel	17.52	18.20	177 (165-190)
P7 mud + API #2 fuel oil (hot-rolled)	17.52	18.20	184 (108-218)
P7 mud + mineral oil	17.52	18.20	538 (446-638)
P7 mud + mineral oil (hot-rolled)	17.52	18.20	631 (580-674)
NBS reference drilling mud	None	0	17,900 (15,816-20,332)
NBS mud + API #2 fuel oil	18.20	18.20	114 (82-132)
NBS mud + API #2 fuel oil (hot-rolled)	18.20	18.20	116 (89-133)
NBS mud + mineral oil	18.20	18.20	778 (713-845)
NBS mud + mineral oil (hot-rolled)	18.20	18.20	715 (638-788)
P1 drilling mud	None	18.20	142 (133-153)

Source: Adapted from Duke and Parrish, 1984.

[a] 95% confidence limits computed by using a "t" value of 1.96.

[b] Properties: Specific gravity at 20°C, 0.86; Pour point -23°C; Viscosity, Saybolt, 38°C, 36; Saturates, wt% 62; Aromatics, wt% 38; Sulfur, wt%, 0.32.

[c] Properties: Specific gravity at 15.5°C, 0.84-0.87; Flash point, 120-125°C; Pour point, -12 to -15°C; Aniline point, 76-78°C; Viscosity, CST 40°C, 4.1 to 4.3; Color Saybolt, +28; Aromatics, wt%, 16-20; Sulfur, 400-600 ppm.

fluid significantly decreased clearing rates, although dose quantification was not possible (Thompson and Bright, 1977, as in Petrazzuolo, 1981). When seven coral species were studied using *in situ* exposures to used drilling fluid (Thompson and Bright, 1980), *Montastrea* and *Agaricia* displayed no mortality after a 96-hour exposure to 316 ppm concentration, but 100 percent mortality at the 1,000 ppm level. Stress reaction were displayed by six species at the 316-ppm exposure level, including partial or complete polyp retraction and mucous secretion. A similar response was observed after a 96-hour exposure to 100 ppm.

Thompson, in an undated report to the USGS, exposed *Montastrea* and *Porites* to used drilling fluids from a well of 4,200 m (13,725 ft) drilling depth. The corals were buried for eight hours under the fluid and then removed to a sand flat to observe recovery. The exposure produced tissue atrophy and decay, formation of loose strands of tissue, and expulsion of zooxanthellae (zooxanthellae are algae living within coral cells in a symbiotic relationship), all indicative of severe stress. The *Montastrea* colonies were dead 15 hours after removal, and the *Porites* colonies were dead after 10 days.

The effects of thin layer application to these species were also observed. *In situ* exposures of drilling mud produced no apparent effects on clearing rates; however, laboratory application did demonstrate effects. Applications of 10-ml thick carbonate sand or drilling fluid from a depth of either 4,200 m (13,800 ft) or 1,650 m (5,413 ft) were applied to the corals, with the following results:

- Colonies in the sand experiment cleared themselves in 4 hours

- Colonies in the 1,650-m fluid experiment cleared themselves in 2 hours

- Colonies in the 4,200-m fluid experiment were 20% (*Montastrea*) and 40% (*Porites*) cleared after 4 hours, 20% (*Montastrea*) and 100% (*Porites*) cleared after 26 hours.

Additional testing with *Porites* indicated that the 4,200-m fluid was more toxic than the 1,650-m fluid, probably because the use of additives increases with well depth. No data are available on actual drilling fluid composition, however.

Krone and Biggs (1980) exposed the coral (*Madracis decactis*) to suspensions of 100-ppm drilling mud from Mobile Bay, Alabama, which had been spiked with 0, 3, and 10 ppm ferrochrome lignosulfonate (FCLS). The drilling mud was presumable one with a low (<1 ppm) FCLS concentration. The corals were exposed for 17 days, at which time they were placed in uncontaminated seawater and allowed to recover for 48 hours. all the corrals exposed to the FCLS-spiked mud exhibited short-term increases in oxygen consumption and ammonia excretion. Photographic documentation of the corals revealed a progressive development of the following conditions: 1) a reduction in the number of polyps expanded indicating little or

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no active feeding; 2) extrusion of zooxanthellae; 3) bacterial infections with subsequent algal overgrowth; and 4) large-scale polyp mortality in two of the colonies. Coral behavior and condition improved dramatically during the recovery period. Polyps of surviving corals reexpanded and fed actively on day two of the recovery period.

Dodge (1982) evaluated the effects of drilling fluid exposure on the skeletal extension of reef-building corals (*Montastrea annularis*). Corals were exposed to 0, 1, 10, or 100 ppm drilling fluid ("Jay" fluid) for 48 days in a flow-through bioassay procedure. The drilling mud composition was changed approximately weekly as new mud taken from the well was added. One significant change in mud composition was in the diesel oil content, which was 0.4% by weight from the fourth week to the end of the experiment. Corals exposed to 100 ppm had significantly depressed linear growth rates and increased mortality. Calcification rates of corals exposed to 100 ppm decreased by 53% after four weeks and by 84% after six weeks. There was no indication of lowered growth rates for either the 1- or 10-ppm exposure.

Hudson and Robbin (1980) exposed corals (*Montastrea annularis*) to unused drilling fluid in heavy doses of 2- to 4-mm layers applied four times at 150-minute intervals. Drilling mud particles were generally removed by a combination of wave action, tentacle cleansing action, and mucous secretions. At the end of the exposure period, corals were placed in protected waters for six months. At the end of another six months, the corals were removed and examined for growth characteristics. Results of the growth analysis indicated that heavy concentrations of drilling mud applied directly to the coral surface over a period of only 7-1/2 hours reduced growth rates and suppressed variability. Trace element analyses of the corals indicated that neither barium nor chromium incorporated into the skeletal materials.

Experiments with the coral *Acropora cervicornis* revealed reduced calcification rates after exposure to concentrations as low as 25 ppm of used Mobile Bay drilling mud (Kendall et al., 1983). Calcification rates in growing tips were reduced to 88%, 83%, and 62% of control values after 24-hour exposures to 25, 50, and 100 ppm (v/v) drilling mud, respectively. Effects on soluble tissue protein and ninhydrin positive substance were also noted at these or higher levels. Further experiments with kaolin, designated to reproduce the turbidity levels of the drilling mud without its chemical effects, revealed slight metabolic changes to the corals that were much less pronounced than those observed for the drilling mud treatments.

5.2.3 Long Term Sublethal Effects

Crawford and Gates (1981) examined the effect of a Mobile Bay drilling mud (mud XVI) on the fertilization and development of the sand dollar *Echinarachnius parma*. Fertilization studies showed that

sperm were highly refractive to the toxic action of this drilling mud. Exposure even at 10,000 mg solids/ml (a 26-fold dispersion of the whole mud) reduced fertilization by only 7 percent. Eggs were more sensitive: exposure to 1,000 mg/ml (262-fold dilution of the whole fluid) reduced fertilization from 88-90 percent to 4-6 percent. No effect was noted at 100 mg/ml (2,620-fold whole mud dilution). At this same exposure level (100 mg solids/ml), no effects were observed in development. At 1,000 to 10,000 mg solids/ml, development was delayed.

No EC50/LC50 ratio could be determined from these data. However, the apparent lower limit of 1,000 ppm drilling mud as the lowest level that results in statistically significant sublethal reproductive changes is consistent with other data. For example, killifish (*Fundulus heteroclitus*) embryos were exposed to a seawater-lignosulfonate mud (Neff et al., 1980). Several parameters were examined, including percentage hatch, percentage increased time to hatch, percentage decreased heart rate, and anomalies at day 16. Although no EC50/LC50 ratios could be calculated, data were available to plot and obtain EC01 values. These ranged from 1,000-6,000 ppm. For the shrimp *Palaemonetes pugio*, exposure to 1,000-10,000 ppm of a high density lignosulfonate mud did not alter the duration of any larval instar (Neff et al., 1980).

The effects of 6-week exposures to the aqueous phases of both medium- and high-density lignosulfonate muds on the condition index (dry meat weight/shell weight) of oyster spat (*Crassostrea gigas*) have been reported (Neff et al., 1980). For the medium-density mud (12.6 lb/gal), no effect was noted at 5,000 ppm or 10,000 ppm whole mud equivalents. The index was reduced about 20 percent at 20,000 ppm. For the high-density mud (17.4 lb/gal), approximately a 30 percent reduction occurred in the index at all concentrations tested.

Mussels (*Mytilus sp.*) were exposed to 50 ppm TSS for 30 days by Gerber et al. (1980). Growth was 75 percent of that observed in control animals. It is not known, however, whether this represents a process of reversible growth retardation or irreversible growth inhibition.

Juvenile mysids were exposed to 15,000-75,000 ppm of the aqueous phase of a lignosulfonate mud for 7 days by Carr et al. (1980). On a dry-weight basis, no effect on respiration occurred. This contrasts with the increased respiration seen in shrimp exposed to 35,000 ppm of the same mud's aqueous phase and suggests that compensatory adaptation had occurred. Average dry weights were significantly lower in exposed shrimp.

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When polychaetes (*Nereis sp.*) were exposed to 100,000 ppm of the aqueous phase of a lignosulfonate mud for 4 days, glucose-6-phosphate dehydrogenase activity was significantly decreased (Gerber et al., 1980). Activity recovered, however, during a 4-day depuration period.

Histologic alterations were noted following exposure of grass shrimp to 100 ppm or 500 ppm barite for 30 days (Conklin et al., 1980). Mortalities in two replicates of the experiment were 20 percent for control shrimp and 60 percent for exposed shrimp (no concentrations of barite given). In 40 percent of the surviving shrimp, there were no histologic changes. In the remainder of surviving shrimp a variety of changes were noted, including: absence of posterior midgut epithelia (20 percent of the survivors); degenerative changes in microvilli; dilated and hypertrophied rough endoplasmic reticulum; and both nuclear and Golgi changes. Barite was also observed in statocysts. Although controls were provided with a sand substrate, exposed shrimp were not. Thus, it remains unclear whether such changes would occur in a sediment-barite mixture. Also, because of concerns over settling of barite particles, no dose-response relationship could be identified or constructed from the data.

Lobsters were exposed to a Jay field fluid (an onshore operation) for 36 days in a flow-through system by Atema et al. (1982). The exposure was nominally at 10 mg/l. However, settling of solids was noted and the actual exposure was undefined. The number of dead or damaged lobsters was not significantly different from controls. The number of dead plus damaged lobsters was significantly higher among treated animals. Although molts from larval stage IV to V were unaffected, molts from stage V to VI were delayed in exposed animals. Exposed lobsters also exhibited poor coordination and food alert suppression.

Three studies in a Gulf of Mexico laboratory have examined the effects of drilling muds or drilling mud components on community recruitment and development of benthic macrofauna (Tagatz et al., 1980; Tagatz and Tobia, 1978) and meiofauna (Cantelmo et al., 1979). Test substances were mixed at various ratios with sediment, or were applied as a covering layer over sediment in a flow-through system.

The tests conducted with drilling mud indicated that annelids were the most sensitive group, exhibiting significant reductions in abundance at 1:10 and 1:5 mixtures of mud and sediment, as well as when exposed to a covering of drilling mud (Tagatz et al., 1980). This sensitivity of annelids was also observed for a similar experiment conducted with barite as the toxicant. Coelenterate abundance was also significantly reduced by exposure to the 1:5 mixture of mud and sediment and the drilling mud covering. Arthropods were affected only by a drilling mud covering. Molluscs were not significantly affected by exposure to drilling mud, but were reduced in abundance when exposed to barite covering (Tagatz and Tobia, 1978). Annelid abundance was also reduced by exposure to barite covering (Tagatz and Tobia, 1978), but not other groups were

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significantly affected. Exposure to barite as a mixture in sediment significantly increased the abundance of nematodes and increased total meiofaunal density, whereas barite layering slightly reduced total meiofauna density and densities of nematodes and copepods. The reduction was not statistically significant (Cantelmo et al., 1979).

Certain difficulties arise in the interpretation of these data. First, results for total abundance are apparently skewed by the greater sensitivity of a certain few predominant species. This does not affect the significance of the results within the constraints of this experiment, but may reduce the applicability of these results to areas *in situ* where community structure is not similar to those observed in this experiment. Second, any attempt to relate these studies to effects *in situ* is confounded by the absence of sediment barium levels given for these studies. Barium is the only useful tracer of drilling mud dispersion in the sediment.

5.2.4 Metals

The potential accumulation of metals in biota represents an issue of concern in the assessment of oil and gas impacts. Sublethal effects resulting from bioaccumulation of these highly persistent compounds are most often measured. Gross metal contamination from drill muds may also cause mortality, particularly in benthic species. Sources of metals include drill fluids, formation waters, sacrificial anodes, and contamination from other minor sources. Drill fluids and formation waters are the primary sources of the metals of concern: arsenic (As), barium (Ba), chromium (Cr), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), vanadium (V), silver (Ag), and zinc (Zn).

Field studies of metal concentration in sediments around platforms suggest that enrichment of certain metals may occur in surface sediments around platforms (Tillery and Thomas, 1980; Mariani et al., 1980; Crippen et al., 1980; and others). In the review of these studies conducted by Petrazzuolo (1983), enrichment of metals around platforms is generally distance dependent with maximum enrichment factors seldom exceeding ten. In platforms studied, enrichment of metals that could be attributed to drilling activities was either generally distributed to 300-500 m around the platform, or distributed downcurrent in a plume to a larger distance from the structure.

The concentrations of metals required to produce physiological or behavioral changes in organisms vary widely and are determined by factors such as the physicochemical characteristics of the water and sediments, the bioavailability of the metal, the organism's size, physiological characteristics, and feeding adaptations. Metals are accumulated at different rates and to different concentrations depending on the

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tissue or organ involved. Laboratory studies on metal accumulation as a result of exposure to drill muds have been conducted by Tornberg et al. (1980), Brannon and Rao (1979), Page et al. (1980), McCulloch et al. (1980), Liss et al. (1980), and others. Data from these laboratory studies are summarized in Table 5-7. Maximum enrichment factors for the metals measured were generally low (<10) with the exception of Ba and Cr, which had enrichment factors of up to 300 and 36, respectively.

Depuration studies conducted by Brannon and Rao (1979), McCulloch et al. (1980), and Liss et al. (1980) have shown that organisms tested have the ability to depurate some metals when removed from a zone of contamination. In various tests, animals were exposed to drill fluids from 4-28 days, followed by a 1-14 day depuration period. Uptake and depuration of Ba, Cr, Pb, and Sr were monitored and showed a 40-90% decrease in excess metal in tissues following the depuration period. Longer exposure generally meant a slower rate of loss of the metal. In addition, if uptake was through food organisms rather than a solute, release of the excess metal was slowed.

The available laboratory data on metals accumulation are difficult to correlate with field exposure and accumulation. Petrazzuolo's review (1983) notes that in the field, bioaccumulation of metals in the benthos will result from exposure to the particulate components of drilling muds. However, laboratory studies have almost always used either whole fluids or mud aqueous fractions, and thus are either over- or underestimating potential accumulation.

Field studies of metal accumulation in marine food webs off southern California have been conducted by Schafer et al. (1982) and others. These data have indicated that most metals measured (including Cr, Cu, Cd, Ag, Zn) do not increase with trophic level either in open water or in contaminated regions such as coastal sewage outfalls. Hg, however, may be an exception to this, as biomagnification has been observed in a number of studies. Brown et al. (1982a; 1982b) have shown that croakers, scorpionfish, and sea urchins can detoxify inorganic metals through a protein synthesis process that excludes contaminants from cellular enzyme pools.

Bioaccumulation of metals in southern and central California offshore waters may not be a significant environmental problem. However, Petrazzuolo (1983) states that due to the persistence of metals, the high toxicity of some metals, the paucity of laboratory data on Hg, and the inability to correlate field and laboratory measures, a finding of no significant potential effect is inappropriate at this time.

Table 5-7. Metal Enrichment Factors in Shrimp, Clams, Oysters, and Scallops Following Exposure to Drilling Fluids and Drilling Fluid Components

Test Organism	Test Substance Concentration (ppm)	Exposure Period (days)	Metals, Enrichment Factor[a]				
			Ba	Cr	Pb	Sr	Zn
Palaemonetes pugio[b] Whole animal not gutted	Barite 5 50 5 50	7, 48-hour replacement (after 14-d depuration) (after 14-d depuration)	150 350 2.2 29			1.3 1.9 1.8 2.2	
Carapace	Barite (500)	8 days post-ecdysis, range = 8-21 (48-hour replacement)	7.7			1.2-2.5	
Hepatopancreas	(500)		13			1.9-2.8	
Abdominal muscle	(500)		12			1.5-2.8	
Carapace Hepatopancreas Abdominal muscle	Barite (500) (500) (500)	106	60-100 70-300 50-120			1.6-7.4 0.03 0.71	
Rangia cuneata[c] (soft tissue)	12.7 lb/gal lignosulfonate fluid (50,000 MAF)	4, static (after 4-dy depuration)	1.4 1.1	1.7 1.2			
	13.4 lb/gal lignosulfonate fluid (100,000 MAF)	16, static (after 1-dy depuration) (after 14-dy depuration)	2.5 1.7 1.6				
	Layered solid phase	4, daily replacement (after 1-dy depuration)	4.3 2.0				
Crassostrea[c] *gigas* (soft tissue)	9.2 lb/gal spud fluid (40,000 MAF)	10, static			2.1		1.1
	(10,000 SPP) (20,000 SPP) (40,000 SPP) (60,000 SPP) (80,000 SPP)	4, 24-hr replacement	2.5 3.0 3.0 5.5 7.4				

Source: Adapted from Petrazzuolo, 1983; footnotes at end of table.

(continued)

Table 5-7. Metal Enrichment Factors in Shrimp, Clams, Oysters, and Scallops Following Exposure to Drill Muds and Drill Mud Components (continued)

Test Organism	Test Substance Concentration (ppm)	Exposure Period (days)	Metals, Enrichment Factor[a]				
			Ba	Cr	Pb	Sr	Zn
Crassostrea gigas (soft tissue) (continued)	12.7 lb/gal lignosulfonate fluid (40,000 MAF)	10, static			2.3		1.4
	(20,000 MAF)	14		2.9			
	(40,000 MAF)	14		3.9			
	(10,000 SPP)	4, 24-hr replacement		2.2			
	(20,000 SPP)			4.4			
	(40,000 SPP)			8.6			
	(60,000 SPP)			24			
	(80,000 SPP)			36			
	17.4 lb/gal lignosulfonate fluid (40,000 MAF)	10, static			0.56		1.0
	(20,000 MAF)	14		2.1			
	(40,000 MAF)	14		2.2			
Placopecten[d] magellanicus	Uncirculated lignosulfonate fluid						
Kidney	(1,000)	28	8.8	2.6			
Adductor muscle	(1,000)	28	10	1.2			
	Low density lignosulfonate fluid						
Kidney	(1,000)	14		1.6			
		27		2.1			
		(after 15-dy depuration)		2.3			
Adductor muscle	(1,000)	14		2			
		27		2			
		(after 15-dy depuration)		2			
	FCLS (30)	14		5.7			
		(after 14-dy depuration)		3.2			
	(100)	14		6.0			
		(after 14-dy depuration)		5.2			
	(1,000)	14		7.2			
		(after 14-dy depuration)		6.0			

[a] Enrichment factor = concentration in exposed group/concentration in controls.
[b] Source: Brannon and Rao, 1979.
[c] Source: McCulloch, et al., 1980.
[d] Source: Liss, et al., 1980.

5.3 TOXICITY OF PRODUCED WATER

In addition to mud and cuttings, produced water constitutes a major discharge from offshore production operations. Water brought up from the hydrocarbon-bearing strata with the produced oil and gas includes brines trapped with the oil and gas in the formation and possibly water injected into the reservoir to increase productivity. (Water injected to increase hydrocarbon recovery is normally injected into wells other than the producing wells.) The actual amount of produced water derived from each site is a function of the geological formation encountered and the method of recovery. The proportion of water in the produced fluids may vary from 0 to over 90% and can increase, decrease, or remain constant over the lifetime of an individual well (Menzie, 1982). In Cook Inlet, produced fluids have increased in water content as most fields have matured. The generation of produced water is a relatively continuous feature of producing platforms, unlike the intermittent discharge of drilling mud and cuttings from exploration, development, and production operations.

Brines are the major form of produced water, and the major inorganic constituents are chlorides. Menzie (1982) reports typical dissolved solids concentrations of 80,000-100,000 mg/l in produced water, although a range from a few mg/l to approximately 300,000 mg/l has been observed. In comparison, seawater of 30 ppt salinity has a dissolved solids concentration of 30,000 mg/l. In upper Cook Inlet, dissolved solids concentrations in produced waters are typically 24,700 mg/l (Lysyj and Curran, 1983).

In most oil fields, treatment of the total fluid to separate oils from produced water ranges from simple gravity separation at offshore facilities to multi-step processes at centralized onshore facilities. Any gas co-produced with the oil is separated out. Use of the multi-step processes can lead to reduction of oil content, volatile aliphate hydrocarbons, and volatile aromatic hydrocarbons. The gas is either flared at the platforms, used for energy, or sold and is not part of the final discharge. Chemical analysis of produced water is described in Section 3.

Potential biological effects occurring as a result of produced water discharges include osmotic stress if salinity varies significantly from ambient sea water, respiratory stress if DO levels are low, bioaccumulation of various components, and toxic effects from hydrocarbon and heavy metal constituents.

The probability of these effects occurring in state waters is a function of total volume discharged within a water mass and the dilution/dispersion of the effluent plume. The latter may be affected by salinity of the discharge. Low saline produced water (relative to ambient seawater) will tend to rise to the surface, whereas briny produced water will tend to sink to the bottom layer. The mixing rates of these types of

discharges depend on current/wave conditions and the density difference between the effluent and the receiving water.

If the salinity of the produced water is similar to ambient sea water, osmotic stress is improbable and respiratory stress is likely to be restricted to localized, nearfield areas. Minimal impact of this type is likely unless the quantity (volume) of discharge is such that DO is measurably depressed within the water mass. This is most likely to occur only in shallow, poorly flushed embayments.

5.3.1 Acute Toxicity

A limited number of studies have examined the toxicity of produced waters. A bioassay program was carried out by Rose and Ward (1981) on produced water from the Buccaneer Field in the Gulf of Mexico off Texas. Results were presented for four series of test conditions. Test series Nos. 1-3 were performed at a shore-based laboratory, while test series No. 4 was conducted on the production platform. The results indicate a range in toxicity of LC50 (concentration lethal to 50% of test organisms) values from 8,000 to 154,000 ppm for invertebrates and 7,000 to 408,000 ppm for the vertebrate tested (Table 5-8).

Given the limited amount of toxicity data for produced waters, it is useful to examine available toxicity data for produced water constituents. Such an examination would not, of course, account for possible synergistic effects among these constituents in whole fluids. Nonetheless, this approach may serve to expand an understanding of the major components of produced water toxicity.

Table 5-9 presents available toxicity data for whole produced waters and individual trace metal and hydrocarbon constituents. Table 5-10 shows the measured range of concentration for each pollutant in undiluted produced water, and indicates for the species listed which acute toxicity values may be exceeded by the discharge concentrations. Mean discharge concentrations for zinc and phenol exceed at least one of the LC50 values for *Mercenaria mercenaria* and *Stolephorus purperens*, respectively. Recent toxicity data with six produced water samples and *Mysidopsis bahia* parallel these results, with 96 hr LC50 values ranging from 13,000 to 93,000 ppm (Table 5-11).

Table 5-8. Median Lethal Concentrations (LC50's) and Associated 95% Confidence Intervals for Organisms Acutely Exposed to Formation Water under Various Experimental Conditions

Organism	Season of test	Formation water used	Testing temp.	LC50[a,b]	95% Confidence interval[a,b]
Test Series No. 1[c]					
Brown shrimp					
Larva	Spring 1979	D	28	10,000	7,000-15,000
		E	28	12,000	9,000-18,000
		F	28	8,000	6,000-12,000
		G	28	8,000	5,000-11,000
Subadult	Summer 1978	A	25±1	94,000	63,000-172,000
	Fall 1978	B	22±1	60,000	0-100,000
	Winter 1979	C	18±2	183,000	130,000-279,000
	Spring 1979	D	24±1	61,000	47,000-76,000
Adult	Summer 1978	A	25±1	94,000	63,000-172,000
	Fall 1978	B	22±1	78,000	38,000-183,000
	Winter 1979	C	18±2	178,000	132,000-240,000
	Spring 1979	D	24±1	90,000	61,000-156,000
White shrimp					
Subadult	Summer 1978	A	25±1	56,000	51,000-62,000
	Fall 1978	B	22±1	61,000	48,000-76,000
	Winter 1979	C	18±1	133,000	67,000-366,000
Adult	Summer 1978	A	25±1	81,000	48,000-153,000
	Fall 1978	B	22±1	62,000	27,000-110,000
	Winter 1979	C	18±1	92,000	58,000-150,000
	Spring 1979	D	24±1	37,000	24,000-52,000
Barnacle	Summer 1978	A	25±1	33,000	25,000-38,000
	Fall 1978	B	22±1	84,000	68,000-104,000
	Winter 1979	C	18±2	154,000	111,000-222,000
	Spring 1979	D	24±1	60,000	49,000-71,000
Crested blenny	Summer 1978	A	25±1	158,000	100,000-320,000
	Fall 1978	B	22±1	408,000	320,000-560,000
	Spring 1979	D	24±1	178,000	135,000-235,000
Test Series No. 2[d]					
Barnacle	Winter 1979	C	18±2	8,000	5,000-13,000
Cr. blenny	Spring 1979	D	24±1	7,000	5,000-12,000
Test Series No. 3[e]					
White shrimp					
Subadult	Fall 1978	B	22±1	62,000	48,000-76,000
Test Series No. 4[f]					
Brown Shrimp					
Subadult	Spring 1979	H	25-29	44,000	25,000-60,000
Barnacle	Spring 1979	H	25-29	51,000	34,000-68,000

Source: Rose and Ward, 1981; footnotes on following page.

(continued)

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Table 5-8. Median Lethal Concentrations (LC50's) and Associated 95% Confidence Intervals for Organisms Acutely Exposed to Formation Water under Various Experimental Conditions. (continued)

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[a] All LC50's and associated 95% confidence intervals are 96-hr values except in the case of larval brown shrimp, for which 48-hr values are reported. Units are ppm formation water.

[b] In most cases, LC50's and related confidence intervals were calculated by the moving average method. However, the binomial method was employed in Test Series No. 1 for subadult brown shrimp tested in the fall as well as for crested blennies tested in the summer and fall. The probit method was used for Test Series No. 4. •

[c] Static laboratory tests; oxygen demand of formation water not evaluated. Except in the case of tests with larval brown shrimp, test and control media were aerated to maintain dissolved oxygen concentration (DO) above 4 mg/l. Aeration was not required to maintain a DO above 4 mg/l in tests with larval shrimp.

[d] Static laboratory tests; oxygen demand of formation water evaluated. Test and control media were not aerated. Although DO of control media remained above 4 mg/l during the tests, DO of test media decreased to 0.5-3.2 mg/l (barnacle) and 1.2-4.0 mg/l (crested blenny) by the end of the 96-hr testing period.

[e] Flow-through laboratory tests; oxygen demand of formation water not evaluated. Test and control media were aerated to maintain DO above 4 mg/l.

[f] Flow-through platform tests; oxygen demand of formation water not evaluated. Test and control media were aerated to maintain DO above 4 mg/l.

Table 5-9. Acute Lethal Toxicity of Produced Waters and
Constituents of Produced Waters to Marine Organisms

Constituent/Species	Life stage	LC50/EC50(ppm)[a]	Reference
PRODUCED WATERS			
Whole produced waters			
Balanus tintinnabulum (Barnacle)[b]	Adult	83,000	NMFS, 1980
Penaeus aztecus (Brown shrimp)[b]	Adult	116,000	NMFS, 1980
	Adult	78,000-178,000	Rose & Ward, 1981
	Subadult	60,000-183,000	Rose & Ward, 1981
	Larvae	9,500 (48-hr LC50)	NMFS, 1980
	Larvae	8,000-12,000 (48-hr LC50)	Rose & Ward, 1981
Penaeus setiferus (White shrimp)[b]	Adult	70,000	NMFS, 1980
Hypleurochilus geminatus (Crested blennie)[b]	Adult	269,000	NMFS, 1980
	Adult	158,000-408,000	Rose & Ward, 1981
Cyprinodon variegatus (Sheepshead minnow)	Adult	550,000-600,000	Andreason & Spears, 1983
TRACE METALS			
Zinc			
Capitella capitata (Polychaete)	Adult	3.5	U.S. EPA, 1980
	Larvae	1.7	U.S. EPA, 1980
Neanthes arenaceodentata (Polychaete)	Adult	1.8	U.S. EPA, 1980
	Juvenile	0.9	U.S. EPA, 1980
Nereis diversicolor (Polychaete)	Adult	11-55	U.S. EPA, 1980
Nereis virens (Sand worm)	Adult	8.1	U.S. EPA, 1980
	Adult	2.6 (168-hr LC50)	U.S. EPA, 1980

[a] 96 -hr LC50/EC50 unless otherwise noted
[b] Species distribution in NOAA data base for commercially important species in the Gulf of Mexico.

(continued)

Table 5-9. Acute Lethal Toxicity of Produced Waters and
Constituents of Produced Waters to Marine Organisms (continued)

Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Ophryotrocha labronica (Polychaete)	Adult	1.0 (13-hr LC50)	U.S. EPA, 1980
Crassostrea virginica (American oyster)[b]	--	0.31	U.S. EPA, 1980
	Larvae	0.75 (48-hr LC0)	U.S. EPA, 1980
	Larvae	0.50 (48-hr LC100)	U.S. EPA, 1980
Mercenaria mercenaria (Hard-shelled clam)	--	0.17	U.S. EPA, 1980
	Larvae	0.20 (10-day LC50)	U.S. EPA, 1980
	Larvae	0.05-0.34 (12-day LC5-LC95)	U.S. EPA, 1980
	Embryo	0.28 (48-hr LC100)	U.S. EPA, 1980
Mya arenaria (Soft-shelled clam)	--	5.2-7.2	U.S. EPA, 1980
	Adult	1.5-3.1 (168-hr LC50)	U.S. EPA, 1980
Mytilus edulis (Mussel)	--	2.5-4.3	U.S. EPA, 1980
Nassarius obsoletus (Mud snail)	Adult	50.0	U.S. EPA, 1980
	Adult	7.40 (168-hr LC50)	U.S. EPA, 1980
Acartia clausi (Copepod)	Adult	0.95	U.S. EPA, 1980
Acartia tonsa (Copepod)	Adult	0.29	U.S. EPA, 1980
Eurytemora affinis (Copepod)	Adult	4.09	U.S. EPA, 1980
Nitocra spinipes (Copepod)	Adult	1.45	U.S. EPA, 1980
Pseudodiaptomus *coronatus* (Copepod)	Adult	1.78	U.S. EPA, 1980
Tigriopus japonicus (Copepod)	Adult	2.16	U.S. EPA, 1980
Mysidopsis bahia (Mysid shrimp)	--	0.50	U.S. EPA, 1980

(continued)

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Table 5-9. Acute Lethal Toxicity of Produced Waters and Constituents of Produced Waters to Marine Organisms (continued)

Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Mysidopsis bigelowi (Mysid shrimp)	--	0.59	U.S. EPA, 1980
Homarus americanus (Lobster)[c]	Larvae	0.18-0.58	U.S. EPA, 1980
Carcinus maenas (Crab)	Larvae	1.0	U.S. EPA, 1980
Pagurus longicarpus (Hermit crab)	Adult	0.4	U.S. EPA, 1980
	Adult	0.2 (168-hr LC50)	U.S. EPA, 1980
Asterias forbesi (Starfish)	Adult	39.0	U.S. EPA, 1980
	Adult	2.3 (168-hr LC50)	U.S. EPA, 1980
Fundulus heteroclitus (Mummichog)	Adult	60	U.S. EPA, 1980
	Adult	60 (96-hr LC28)	U.S. EPA, 1980
	Adult	10.0-20.0 (168-hr LC50)	U.S. EPA, 1980
	Adult	157 (48-hr LC100)	U.S. EPA, 1980
	Adult	43 (192-hr LC0)	U.S. EPA, 1980
	Adult	66 (192-hr LC50)	U.S. EPA, 1980
	Larvae	83	U.S. EPA, 1980
Menidia menidia (Atlantic silverside)	Larvae	2.73-4.96	U.S. EPA, 1980
Pseudopleuronectes americanus (Winter flounder)[c]	Larvae	4.92-18.2	U.S. EPA, 1980

HYDROCARBONS

Petroleum alkanes

Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Crassostrea virginica (American oyster)[b]	Adult	33-154	Brooks et al., 1980
Penaeus aztecus (Brown shrimp)[b]	Subadult	56-133	Brooks et al., 1980
Penaeus duorarum (Pink shrimp)[b]	Subadult	56-133	Brooks et al., 1980

(continued)

[c] Species distribution data in NOAA data base for commercially important species in the Atlantic OCS.

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Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Penaeus setiferus (White shrimp)[b]	Adult	37-92	Brooks et al., 1980
Benzene			
Crassostrea gigas (Pacific oyster)	--	924	U.S. EPA, 1980
Tigriopus californicus (Copepod)	--	450	U.S. EPA, 1980
Nitocra spinipes (Copepod)	--	82-111 (24-hr LC50)	U.S. EPA, 1980
Crago franciscorum (Bay shrimp)	--	17.6	U.S. EPA, 1980
Palaemonetes pugio (Grass shrimp)	--	27	U.S. EPA, 1980
	Adult	33.5-40.8 (24-hr LC50)	U.S. EPA, 1980
	Larvae	74.4-90.8 (24-hr LC50)	U.S. EPA, 1980
Cancer magister (Dungeness crab)	Larvae	108	U.S. EPA, 1980
Morone saxatilis (Striped bass)	--	5.1-10.9	U.S. EPA, 1980
Toluene			
Nitocra spinipes (Copepod)	--	24.2-74.2 (24-hr LC50)	U.S. EPA, 1980
Crassostrea gigas (Pacific oyster)	--	1,050	U.S. EPA, 1980
Mysidopsis bahia (Mysid shrimp)	--	56.3	U.S. EPA, 1980
Crago franciscorum (Bay shrimp)	--	3.7	U.S. EPA, 1980

(continued)

Table 5-9. Acute Lethal Toxicity of Produced Waters and
Constituents of Produced Waters to Marine Organisms (continued)

Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Palaemonetes pugio (Grass shrimp)	--	9.5	U.S. EPA, 1980
	Adult	17.2-38.1 (24-hr LC50)	U.S. EPA, 1980
	Larvae	25.8-30.6 (24-hr LC50)	U.S. EPA, 1980
Oncorhynchus kisutch (Coho salmon)	--	10-50	U.S. EPA, 1980
Morone saxatilis (Striped bass)	--	6.3	U.S. EPA, 1980
Oncorhynchus gorbuscha (Pink salmon)	fry	5.4	Thomas & Rice, 1979
Phenol			
Palaemonetes pugio (Grass shrimp)	--	5.8	U.S. EPA, 1980
Crassostrea virginica (Eastern oyster)[b]	--	58.2	U.S. EPA, 1980
Mercenaria mercenaria (Hard clam)	--	52.6	U.S. EPA, 1980
Kuhlia sandvicensis (Mountain bass)	--	11	U.S. EPA, 1980
Salmo gairdneri (Rainbow trout)	--	6.9 (48-hr LC50)	U.S. EPA, 1980
Stolephorus purpureus (Nehu)	--	0.51 (12-hr LC50)	U.S. EPA, 1980
Naphthalene			
Neanthes arenaceodentata (Polychaete)	--	3.8	U.S. EPA, 1980
Crassostrea gigas (Pacific oyster)	--	199	U.S. EPA, 1980

(continued)

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Table 5-9. Acute Lethal Toxicity of Produced Waters and
Constituents of Produced Waters to Marine Organisms (continued)

Constituent/Species	Life stage	LC50/EC50(ppm)	Reference
Palaemonetes pugio (Grass shrimp)	-- --	2.6 (24-hr LC50) 2.4	U.S. EPA, 1980 U.S. EPA, 1980
Penaeus aztecus (Brown shrimp)[b]	--	2.5 (24-hr LC50)	U.S. EPA, 1980
Cyprinodon variegatus (Sheepshead minnow)	--	2.4 (24-hr LC50)	U.S. EPA, 1980
Oncorhynchus gorbuscha (Pink salmon)	fry	0.9 (24-hr LC50)	Thomas & Rice, 1979

Table 5-10. Acute Lethal Toxicity Values (LC50/EC50) Which May be
Exceeded by Measured Discharge Concentrations of Pollutants in Produced Waters

Pollutant	Discharge Concentrations (ppm)[a] Range (mean)	Species	LC50/EC50 (ppm)[b]
Zinc	0.005-0.519 (0.168)	Crassostrea virginica	0.31
			0.50 (48-hr LC100)
		Mercenaria mercenaria	0.17
			0.20 (10-day LC50)
			0.05-0.34 (12-day LC50)
			0.28 (48-hr LC100)
		Arcatia tonsa	0.29
		Mysidopsis bahia	0.50
		Homarus americanus	0.18-0.58
		Pagurus longicarpus	0.4
			0.2 (168-hr LC50)
Benzene	0.002-12.2 (2.98)	Morone saxatilis	5.1-10.9
Toluene	0.060-19.8 (2.07)	Crago franciscorum	3.7
		Palaemonetes pugio	9.5
			17.2-38.1 (24-hr LC50)
		Oncorhynchus kisutch	10-50
		Oncorhynchus gorbuscha	5.4
		Morone saxatilis	6.3
Phenol	0.065-20.8 (2.34)	Palaemonetes pugio	5.8
		Kuhlia sandvicensis	11
		Salmo gairdneri	6.9 (48-hr LC50)
		Stolephorus purpurens	0.51 (12-hr LC50)
Naphthalene	0.019-1.45 (0.187)	Oncorhynchus gorbuscha	0.92 (24-hr LC50)

[a] Discharge concentrations from the 30-platform study (U.S. EPA, 1983).
[b] 96-hr LC50 (EC50) assumed unless otherwise noted.

**Table 5-11. Acute Toxicity Data of Six Produced Water Samples
from the Gulf of Mexico Region to the Mysid, *Mysidopsis bahia***

Sample	96-hr LC50 (ppm)[a]	95% Confidence Limit (ppm)
1	37,000	25,000-47,000
2	31,000	24,000-39,000
3	19,000	13,000-29,000
4	93,000	74,000-119,000
5	51,000	37,000-69,000
6	83,000	67,000-105,000

[a] Values from R.M. Montgomery, personal communication on results of produced water analysis conducted for EPA/OSW, in report to Congress on the RCRA exemption of oilfield wastes.

5.3.2 Chronic and Sublethal Toxicity

Although the acute toxic effects of produced water appear to be low (when biocides are absent), chronic lethal and sublethal effects must be considered. Such effects are expected to occur at concentrations below those that are acutely toxic. Chronic exposures to organisms in the water column could occur in areas where the hydrocarbons discharged to the water column are not rapidly removed from the system and where there is a continuous input. The potential for build-up of hydrocarbons in the water column would be greater in semi-enclosed coastal embayments with limited flushing than in offshore regions.

In areas where a hypersaline produced water plume contacts the bottom, mortality can be expected to occur as a result of anoxic and hypersaline conditions. The extent of these effects will depend on the duration, volume, and dispersion of the plume. It is likely that the benthic community, especially infauna and less mobile epifauna, would be severely disrupted in the immediate vicinity of the discharge. Armstrong et al. (1979) noted severe disruption of benthos within 150 m (490 ft) of the discharge point in Trinity Bay, Texas.

Farther from the discharge site, chronic effects may occur and are likely to impact benthos over a larger area. Chronic effects may occur primarily from exposure to dissolved or deposited metals and hydrocarbons. In other areas it has been noted that compounds at very low concentrations in produced water, especially substituted naphthalenes, can accumulate to high concentrations in sediments and in biota (Armstrong et al., 1979). This occurs even in areas where the discharge plume dilutes rapidly (Armstrong et al., 1979).

5.4 BIOACCUMULATION POTENTIAL OF PRODUCED WATER

The environmental accumulation potential of selected trace metal and organic constituents of produced waters has been previously estimated from predetermined sorption coefficients (K_d) and bioconcentration factors (BCF). This data, derived from the ODCE for Southern California (U.S. EPA, Region 9, 1984), is presented in Table 5-12. It can be seen that the affinity of trace metals to suspended particulate matter or sediments (i.e., their partitioning potential) is very high. Among the elements listed, Pb, Mn, and Hg have the highest coefficient value; Cr, Cu, Ag, and Zn comprise a group which has medium partitioning potential; Sb, As, Fe, Cd, Ni, Se, and Tl show the lowest potential as compared to the other elements. The range of BCF values for each element is large and therefore definitive patterns cannot be deciphered. However, looking at the maximum estimated values, it appears that Zn, Tl, Hg, and Cd exhibit.

Table 5-12. Estimated Accumulation Factors of Selected
Trace Metals and Petroleum Components in Produced Waters

Component	Sorption[a] Coefficient (K_d x 10[4])	Bioaccumulation[b] Factor (BCF x 10[4])	Relative Accumulation Potential
Trace Metals			
Antimony	2	0.004-2	L
Arsenic	2	0.03-2	L
Beryllium	1	0.01	L
Cadmium	6	0.01-10	M
Chromium	30	0.001-0.1	M
Copper	20	0.01-1	M
Lead	90	0.001-0.01	MH
Manganese	100	NA	UND[c]
Mercury	250	0.1-10	H
Nickel	8	0.001-0.1	L
Selenium	6	0.01	L
Silver	20	0.01-0.1	M
Thallium	3	0.001-10	MH
Zinc	20	0.01-10	MH
Hydrocarbons			
Benzene	0.0019	0.0045	L
Toluene	0.0023	0.0052	L
Xylene	NA	NA	UND
Naphthalene	0.026	0.035	ML
Anthracene	0.25	0.035	M
Phenanthrene	0.30	0.22	M
Benzo(a)pyrene	15.14	0.1	H
Ethylbenzene	NA	NA	UND
Acenaphthalene	0.12	0.12	M

Source: U.S. EPA, Region 9, 1984.

[a] Sorption coefficients for trace metals were determined from field measurements in estuarine waters; coefficients for the organic constituents were estimated from octanol/water partition coefficient.
[b] Bioaccumulation factors for trace metals were estimated from Versar (1979); trace organics were estimated from octanol/water partition coefficients.
[c] UND = Undetermined.

the highest bioaccumulation potential, with Sb, As, and Cu sharing a medium tendency and Ag, Se, Ni, Pb, Cr, and Be exhibiting the lowest values.

For trace organic constituents listed in the table, benzo(a)pyrene has the highest sorption value followed by three compounds having similar K_d values (acenaphthalene, phenanthrene and anthracene) but of lower magnitude (one to two orders of magnitude). Benzene and toluene, being volatile compounds have the least tendency for sorption. All of the listed compounds except the volatiles and naphthalene show similar bioaccumulation capacity.

Based on magnitude of the K_d and BCF values listed in Table 5-12, each of the constituents were ranked according to their relative environmental accumulation potential. The rankings are designated as: high (H), medium (M), low (L) and combinations among these. These rankings coupled with the rankings for toxicity should present a first approximate determination of which compounds appear to be of concern.

5.5 SUMMARY

It has also been shown by U.S. EPA, 1980; and Rize et al., 1976 that several produced water constituents and the water soluble fraction of crude oil can be toxic to marine organisms at levels of 0.31 ppm (Zinc) and 0.81 ppm (water soluble fraction). Hydrocarbons are known to absorb to sediment and may often remain for years (Platt and Mackie, 1980). Armstrong et al. (1979) noted definite correlations in Trinity Bay, Texas between sediment naphthalene concentrations from brine effluent in the vicinity of an oil separator platform and the number of benthic species and individuals. Effluent production ranged from 4,100-10,000 bbl/day, with an average salinity of 64 ppt and average oil concentrations of 15 ppm (1.62 ppm naphthalenes). The sediment was nearly devoid of organisms within 15 m (49 ft) of the outfall, with "severely depressed benthic fauna" to 150 m (460 ft) from the outfall. A "low, possibly 2 ppm, persistent concentration of naphthalenes" was considered capable of restricting many species (Armstrong et al., 1979). The accumulation of hydrocarbons and the disruption of benthic populations occurred rapidly and persisted for as much as 6 months in Trinity Bay, Texas (Armstrong et al., 1979). The use of a number of outfalls was also noted to be more harmful than a single outfall. Location of the outfall only 1 m from the bottom, however, makes extrapolation of this study to other areas questionable.

It is impossible to predict the extent to which benthos may be affected for any given volume of produced water discharged, due to uncertainties of well locations, variations in chemical composition of produced water, and differing plume characteristics. Acute toxic effects are more likely when the effluent plume is hypersaline and resists dilution and dispersion, but bioaccumulation and toxicity can occur even when dilution is great (Armstrong et al., 1979).

6. BIOLOGICAL OVERVIEW

6.1 PRIMARY PRODUCTIVITY

6.1.1 Phytoplankton

Phytoplankton distribution and abundance in the Gulf of Mexico is difficult to measure. Shipboard or station measurements cannot provide information about large areas at one moment in time, and satellite imagery cannot provide definitive information about local conditions which may be important. Due to fluctuations in the availability of light and nutrients and phytoplankton's lack of mobility, phytoplankton distribution is temporally and spatially variable. Seasonal fluctuations in location and abundance are often masked by patchy distributions which human sampling designs must attempt to interpret. In addition, methods of measurement of chlorophyll or carbon uptake cannot always resolve all questions concerning variability among species, within species under different conditions, and the amount of grazing which occurs.

Nevertheless, phytoplankton's place at the base of the food chain as the primary producers of our oceans, makes their understanding vital to the knowledge of higher levels. In the Gulf of Mexico (especially off the South Texas coast), phytoplankton are often closely associated with bottom organisms, and may even contribute to benthic food sources for demersal feeding fish.

The central Gulf of Mexico has been classified as oligotrophic by many researchers, (MMS, 1983a; Trees and El-Sayed, 1986) with inshore areas being more productive than offshore areas. Chlorophyll maxima have been associated with the pycnoline (Hobson and Lorenzen, 1972; Iverson and Hopkins, 1981; Bird, 1983), fronts at shelf breaks (Trees and El-Sayed, 1986; Bird, 1983; Yentsch, 1982), areas of vertical mixing (Yentsch, 1982), and the nepheloid layer which exists off the south Texas coast during the summer and fall (Flint and Rabalais, 1981; Kamykowski and Bird, 1981; Bird, 1983). Phytoplankton seasonality has been explained in terms of salinity, depth of light penetration, and nutrient availability. In general, the western Gulf is considered more productive than the eastern Gulf (MMS, 1983a; Trees and El-Sayed, 1986).

The FAO Atlas of the Living Resources of the Seas shows high primary productivity slightly west of the Mississippi River (>500 mg $C/m^2/d$) and along the north Texas coast (offshore 250-500 mg $C/m^2/d$),

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and the central Gulf (100-150 mg C/m^2/d). Other mean Gulf of Mexico figures, representative of productivity in the oceanic waters of the Gulf, are:

Productivity in the oceanic waters of the Gulf:

- 0.1 g C/m^2/d yielding 17 g C/m^2/yr or 86 million tons of phytoplankton biomass (MMS, 1983a);
  103-250 g C/m^2/yr (Flint and Kamykowski, 1984);
  103 g C/m^2/yr (Flint and Rabalais, 1981).

Chlorophyll measurements in the Gulf include:

- Predominantly oceanic waters;
  0.05-0.30 mg Chl a/m^3 (MMS, 1983a)
  0.05-0.1 mg Chl a/m^3 (Yentsch, 1982)
  0.22 mg Chl a/m^3 (El-Sayed, 1972)
  0.17 mg Chl a/m^3 (NOAA, 1980 from Trees and El-Sayed, 1986)

- Coastal areas;
  - near the Mississippi
    2.73 mg/Chl a/m^3 (Fucik, from Trees and El-Sayed, 1986)
    3.3 mg/Chl a/m^3 (Trees, 1986)
    10 mg/Chl a/m^3 (Yentsch, 1982)

  - in Southern Texas
    3.11 mg/Chl a/m^3 (Park, 1975, from Iverson, 1981)

Less phytoplankton research has been conducted off the Louisiana coast than off Texas. Phytoplankton extinction areas are often noted near the Mississippi River mouth, which may be due to turbidity of such levels that lack of light or inability to locate nutrients among the inorganic particulate matter inhibit phytoplankton growth (Iverson and Hopkins, 1981; Trees and El-Sayed, 1986; Yentsch, 1982). Mississippi River flow and associated turbidity is especially high in the winter and spring. Abundance usually rises again within 80 km of shore (Iverson and Hopkins, 1981).

Off the South Texas coast, the research of several groups of investigators have shown that the area is one of high primary productivity. Chlorophyll levels are higher (and more variable in the nanophytoplankton category) inshore than offshore and are higher in the northern areas than in southern areas. Chlorophyll levels are also higher in surface waters. Fresh water is believed to be one of the most influential variables that determine chlorophyll levels. It divides the shelf into three regions. The inshore band (0-14 km) is dominated by Texas river waters, and chlorophyll is not consistently correlated to salinity or other parameters. The middle band (14-59 km) is a mix of Texas river and Mississippi River waters, with the 41 km line marking the division of dominance of each. The offshore area (beyond 59 km) is dominated by

Mississippi River water. Productivity is highest in waters under 30 ppt (Flint and Rabalais, 1981) and these low salinities are often associated with a plume of Mississippi River water which washes along the coast, sometimes covering the whole shelf during the winter and spring. Bimodal peaks (spring and fall) have been noted by several investigators, but the exact dates of these peaks vary from year to year (Randall and Hahn, 1981; Flint and Rabalais, 1981; Trees and El-Sayed, 1986). Some investigators have found net phytoplankton to be the most variable phytoplankton component in abundance (Flint and Rabalais, 1981), while others have found higher variability in the nanoplankton (Bird, 1983).

Additional research has demonstrated that surface phytoplankton levels are low during the summer and fall. At these times, a thermocline exists and a turbid nepheloid layer of variable thickness hovers above the bottom. When the photic zone extends through the water column, chlorophyll concentrations are highest in this deep nepheloid layer. The 70-meter contour marks the extent of this occurrence (Kamykowski and Bird, 1981). In winter and spring, surface populations increase again, with concentrations decreasing with depth (Kamykowski and Bird, 1981; Bird, 1983; Flint and Rabalais, 1981). The concentration of phytoplankton around the nepheloid layer is also associated with high concentrations of grazing zooplankton (Bird, 1983). The proximity of phytoplankton to the bottom at these points, and the concentration of nutrients, phytoplankton, and zooplankton in the restricted water column below the thermocline, has led researchers to propose a strong coupling between phytoplankton and the benthos. They believe that nutrient regeneration in the sediments leads to high primary carbon fixation on the Texas shelf and that the bottom may serve as a nutrient reservoir, buffering fluctuations in all other sources. Flint and Rabalais (1981) discuss the correlations between primary producer biomass and densities of benthic infauna and bacteria which may be linked through the detrital pool. The important commercial fisheries for *Penaeus* spp. shrimp may benefit more directly from primary productivity than previously thought. The following is a list of the types of phytoplankton found in Texas and Louisiana waters.

South Texas:

Kamykowski and Bird (1981) ----- Dominant species within the nepheloid layer: *Gyrosigma* sp. Hassal, *Hemiaulus hauckii* Grunow, *Nitzschia paradoxa* Grunow, *Rhizosolenia stolterfothii*, Guinardia flaccida, Hemiaulus emmbranacaceus, Gonyaulax polygramma, *Navicula membranacea, Diploneis, Nitzschia bilobata, Thalassionema nitzschioides, Chaetoceros affinis, Rhizosolenia delicatula*, and *Thalassiosira aestivalis.*

Randall and Hahn (1981) ----- 36 taxa, 7 dominant: Chaetoceros, Coscinodiscus, dinoflagellates, Navicula, Nitzschia, Rhizosolenia, Thalassiosira.

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Flint and Rabalais (1981) ----- Counted only net plankton from December to April: diatoms, dinoflagellates, silicoflagellates, coccolithophorids, blue green algae. Found approximately: 28 species/liter, 80,000 cells/liter, 4.99 mg/m^3/hr total carbon production, 0.64 μg/l Chl a (highest figures in winter).

Louisiana:

MMS (1983) from LOOP, 1975 ----- 35 species and 26 genera, 69 km west of the mouth of the Mississippi River. Density ranged 0-30.5 x 10^3 cells/liter.

Simmons and Breuer (1962) ----- from the eastern Mississippi Delta, a low salinity regime dominated by two species of each of the genera Cyclotella, Melosira, Navicula. At a higher salinity regime; *Nitzschia serate, Thalassiothrix frauenfeldii, Thalassionema nitzochioides, Skeletonema costatum, Asterionella japonica,* and three spp. of *Chaetoceros.*

6.1.2 Macrophytes and Algae

The coastal wetlands and estuarine waters of the Gulf of Mexico contribute significantly to total primary productivity in the territorial seas. It has been estimated that macrophyte production may comprise 75% of total plant production in estuarine-wetland complexes (Thayer and Ustach, 1981). In addition, epiphytic and macrobenthic algae, as well as microalgae on mud surfaces also contribute to the productivity of these inner waters. Macroalgae and epiphytes may comprise 25% of total production in a wetland habitat. Phytoplankton chlorophyll and production in Gulf coast estuaries may be as high as 7 mg Chl a/m^3, and 300 g C/m^2/yr (Thayer and Ustach, 1981). The eventual fate of primary productivity in these systems is not completely clear. The extent of export of detrital matter from wetland systems to estuarine and coastal waters is believed to be high in some cases, and contributes greatly to benthic ecology. By reducing current velocities, the roots in wetland and estuarine areas promote filtration of fresh water entering the sea, and reduce erosion of coastal areas. The roots also provide habitat for algae and juvenile fish and invertebrates, and the above ground structures provide refuge for algae and terrestrial animals and birds.

Of the 7.9 x 10^6 acres of estuarine area around the Gulf of Mexico, Louisiana contains 43% and Texas 19%. Gulf tidal marsh area is estimated at 6 x 10^6 acres, with Louisiana holding 64% within its boundaries, and Texas 16%. Submergent seagrasses are relatively prevalent in Texas (8% of total Gulf; MMS 1983a), though only narrow bands or scattered patches are found from Louisiana to Copano-Aransas,

Texas. Louisiana has well developed grass beds. Mangroves, another coastal community in the Gulf of Mexico, are not prevalent in Louisiana or Texas, though some black mangroves can be found in Texas.

In Louisiana, brackish water marshes dominated by *Spartina patens* represent about 45% and marshes dominated by *Spartina alterniflora*, *Salicornia* spp., and *Juncus* spp. represent about 30% of total marsh land.

Thayer and Ustach (1981) compiled the following data on primary productivity for coastal wetland systems:

Salt Marshes	200-2000 g C/m²/yr	(Turner, 1976)
Mangroves	400 g C/m²/yr	(Thayer et al., 1979)
Seagrasses	100-900 g C/m²/yr	(Thayer et al., 1979)
Spartina alterniflora	1300 g C/m²/yr	(Kirby, Gosselink, 1976)
Other Louisiana spp.	700-3000 g C/m²/yr	(Hopkinson et al., 1978)
Thalassia	580-900 g C/m²/yr	
Phytoplankton	350 g C/m²/yr	

6.1.3 Zooplankton

Like phytoplankton, zooplankton are seasonal and patchy in their distribution and abundance. Zooplankton standing stocks have been associated with the depth of maximum primary productivity and the thermocline (Ortner et al., 1984). These two factors are often correlated, especially in discoveries of phytoplankton and zooplankton concentrations in the deep nepheloid layers of southern Texas. Zooplankton feed on phytoplankton and other zooplankton, and are important intermediaries in the food chain as prey for each other and larger fish. On the south Texas shelf, isothermal conditions that exist during portions of the year allow great vertical mixing and close proximity of pelagic and benthic systems. Here there is a close relationship between zooplankton and the sediment detrital pool (Flint and Rabalais, 1981). As in many marine ecosystems, zooplankton fecal pellets contribute significantly to the detrital pool. The ease of mixing in Gulf coastal waters, may make them extremely important to nutrient circulation and primary productivity, as well as benthic food stocks. Also contributing to the detrital pool is the concentration of zooplankton in bottom waters, coupled with phytoplankton in the nepheloid layer during times of greater water stratification.

Research on the southern Texas shelf indicates that zooplankton biomass, total density, and variability decreases with distance from shore. Conversely, species diversity increases. A north-south variability exists, although it is patchy in deeper waters. At shallow stations, changes in icthyoplankton are correlated with variation in zooplankton more than any other factor. Salinity is the major factor that determines zooplankton variability at mid depth stations, and phytoplankton density at the deep stations. These results may indicate that offshore populations are controlled by food availability, while inshore populations are more affected by predation (Flint and Rabalais, 1981).

Copepods are the dominant zooplankton group found in all Gulf waters, and particularly in south Texas waters. They can account for as much as 70% by number of all forms of zooplankton found (NOAA, 1975). In shallow waters, peaks occur in the summer and fall (NOAA, 1975), or in spring and summer, (MMS, 1983a). When salinities are low, estuarine species such as *Acartia tonsa* become abundant. The NOAA Environmental Studies of the South Texas Outer Continental Shelf found Copepoda, Larvacea (regularly among all stations), Ostracoda (especially at the two deep stations), Mossusca (at two shallow stations) and Chaetognatha (at all stations). Among the copepods, calanoids (70 spp.), Cyclopoida (41 spp.), and Harpacticoida (7 spp.) were prevalent, many of the calanoids (50%) and Cyclopoida (20%) being in developmental stages. At all stations *Paracalanus indicus* and *Paracalanus quasimoto* were the most abundant. Flint and Rabalais (1981) were able to discern depth related groupings of copepod species which are similar to lists of other researchers:

- All depths: *Paracalanus quasimoto, P. indicus, Temora turbinata, Centropages velificatus, Corycaeus americanus, P. Aculeatus, Clausocalanus jobei, Farranula gracilis, Oncaea venusta, Clausocalanus furcatus.*

- Shallow waters: *Eucalanus pileatus, Corycaeus amazonicus, Corycaeus giesbrechti, Acartia tonsa.*

- Middepths: *Nanocalanus minor*

- Deep waters: *Oithona plumifera, Oncaea mediterranea, Calocalanus pavo, Oithona setigera, Lucicutia flavicornis.*

Casey (1976; from Iverson, 1981) noted that radiolarian densities increased with depth, spumellarians dominating inshore and nassellarians offshore.

Flint and Rabalais (1981) report the following average zooplankton densities:

copepod species/m^3 = 41
copepod individuals/m^3 = 536
calanoid individuals/m^3 = 607
larvacea/m^3 = 49
cladocera/m^3 = 29

Randall and Hahn (1981) report copepod densities (primarily *Acartia tonsa*) at 35,000 to 55,000 organisms/m^3. Park (1975, from Iverson, 1981) reports total zooplankton individuals of 2,757 to 760/m^3 (nearshore to offshore) and copepods 2,146 to 534/m^3 (nearshore to offshore). Few studies exist on zooplankton populations in the waters of Louisiana. Generally, genera and species can be assumed to be relatively similar to those found in Texas waters, with estuarine species predominating.

Icthyoplankton, as reported in the NOAA (1975) study, are most abundant in August and September, and least abundant in December and January. Most, approximately 71%, are available near the surface at night. Codlets (Bregmacerotidae) were abundant in the spring, and increase (as do lanternfish) with distance from shore and depth. Herrings (Clupleidae) and anchovies (Engraulidae) are more prevalent nearshore and at intermediate depths. Their abundance is quite high in spring, but by late fall both have disappeared. NOAA found 49 families, 84 genera, and 50 species, with anchovies, codlets, and gobies comprising 57% of total larvae. Though family trends are noted, individual species within a family vary from the trends. *Penaeus* spp. larvae peak in spring, late summer and early fall in nearshore areas. In deeper zones, fall and winter are times of greatest abundances. In general, intermediate zones, from 23 to 82 km, have the highest average abundances.

6.2 BENTHIC FAUNA

The distribution of benthic fauna in the coastal waters of the Gulf of Mexico is correlated primarily with physical factors, and substrate is the most important. In general, benthic habitats can be described primarily on the basis of sediment texture and depth. Depth or distance from shore is a major influence on the type of sediment and benthic fauna found in a given habitat. Other important factors in determining benthic distribution include temperature, salinity, illumination, exposure to air, nutrient availability, currents, tides, and wave shock.

Because the distribution of benthic species is so closely tied to substrate type, it is convenient to divide the area of interest into marsh, estuarine, and continental shelf habitats and to describe the benthic communities which characterize these communities in the Texas and Louisiana territorial seas.

6.2.1 Marsh Communities

The description of marsh communities which follows was taken primarily from a study of the Tuscaloosa Trend region of the Gulf of Mexico (Vittor and Associates, 1985), which includes the coastal marshes of eastern Louisiana.

The coastal marsh meiofaunal community includes nematodes, harpacticoid copepods, kinorhynchs, ostracods, small polychaetes, and some insect larvae (Vittor and Associates, 1985). It also includes larvae and juveniles of larger species. Nematodes are by far the dominant fraction, comprising as much as 90% of the total meiobentic organisms (Rogers, 1970). Most meiofauna in the marsh community are deposit feeders, feeding on bacteria and particles of organic detritus which make up much of the upper layer of marsh sediments (Vittor and Associates, 1985).

Marsh macroinfauna include polychaetes, molluscs, and crustaceans. Dominant polychaete species include *Manayunkia* spp., *Nereis succinea, Parandalia americana, Laeonereis culveri*, and *Heteromastus filiformis*. The dominant bivalve species include *Rangia cuneata*. Dominant crustaceans include *Mysidopsis almyra, Edotea montosa, Cyathura polita* and *Corophium louisianum* (Vittor and Associates, 1985). Macroinfauna are most abundant along marsh channels and ponds, where flowing water provides greater aeration of marsh sediments and where biological production is greater.

Marsh macroepifaunal communities include bivalves, gastropods and crustaceans. The predominant bivalve species include *Modiolus demissus, Crassostrea virginica* and *Brachidontes recurvus*. Gastrapods are dominated by such species as *Neritima reclivata, Littorina irorata* and *Melampus bidentata*. Dominant crustaceans include *Panopeus herbstii, Rithropanopeus harrissii, Sesarma reticulatum, Menippe mercenaria, Uca* spp., *Callinectes sapidus* (juveniles), and *Palaemonetes* spp. (Vittor and Associates, 1985). Most of the motile species move through the marsh with the ebb and flood tides while sessile organism's habitats are defined by inundation.

6.2.2 Estuarine Communities

The meiofauna of estuarine waters are composed of larval and juvenile metazoans (temporary meiofauna) and adult metazoans (permanent meiofauna), such as nematodes, kinorhynchys, harpacticoid copepods, gastrotrichs, etc.

In the Tuscalusa Trend study area (eastern Louisiana) the major estuarine meiofaunal species include harpactecoid copepods, nematodes, gastrotrichs, kinorhynchs, mollusks, and tardigrades. Two distinct meiofaunal communities are believed to occur in estuarine waters of the Tuscalusa Trend area. These communities are characterized based on physical habitat. Habitats characterized by fine sediments (mud) tend to support greater numbers of individuals, especially nematodes which comprise greater than 90% of the composition. Sand habitat meiofauna are richer in species diversity. In both the sand-dwelling and mud-dwelling meiofaunal communities there are seasonal variation in populations, with peaks in late summer and declines in winter.

Many natural and man-made factors influence macrofaunal species distribution and density in estuarine areas. These factors include: temperature, salinity, dissolved oxygen, seasonality, wave shock, prevailing current patterns and intensity, substrate type, and pollution.

The shallow estuarine waters of eastern Louisiana are characterized by a poorly sorted silt (mud) substrate. The microinfauna of the region are characterized by polychaetes (*Polydora ligni, Leitoscoloplos* spp., and *Pamandalia americana*), molluscs (*Nassarius acutus* and *Haminoea succinea*), isopods (*Edotea montosa*), and hemechordates (*Balanoglossus* spp.). The microinfauna are typically dominated by polychaetes (*Myriochele oculata, Owenia fusiformis, Mediomastus* spp., and *Paraprionospio pinnata*) and molluscs (*Mulinia lateralis*).

In the deeper water of Chandeleur and Breton Sounds of eastern Louisiana, the sediment is characterized by less mud and organic content. Microinfauna taxa characteristic of this area include polychaetes (*Cossura soyeri, Magelona* cf. *phyllisae, Nereis micromma*), molluscs (*Nuculana concentrica*), ophiuroids (*Hemipholis elongata, Micropholis atra*) and sipunculids (*Phascolion strombi*). Dominant taxa in the area include the same species as those found in the shallower coastal margins as well as the polychaetes, (*Cossura soyeri; Nereis micromma, and Lumbrineris* spp.); the sipunculid, (*Phascolion strombi*); and the pelecypod, (*Nuculana concentrica*).

Between all barrier islands and in some areas within Chandeleur and Breton Sounds the predominant sediment is moderately sorted fine sands and the taxa in these areas are represented by typical sand dwellers. Representative species include polychaetes (*Polygordius* spp., Poecilochaetus johnsoni, Armandia maculata, and *Spiophanes bombyx*), cephalochordates (*Branchiostoma caribaeum*) pelecypods (*Crassinella lunulatata*), and amphipods (*Acanthohaustoruis* spp., *Protohaustorius* spp., and *Lepidactylus* spp.)

A major component of the estuarine benthic fauna of eastern Louisiana is the macroepifauna. The dominant mobile taxa in the macroepifauna are the gastropods (*Thais haemostoma, Polinices lunulata*), crustaceans (*Clibanarius vittatus, Rhithropanapeus harrissii, Neopanope texana, Panopeus herbstii*, and *Libinia* spp.) and echinoderms (*Luidia clathrata*, and *Mellita quinquiesperformata*). Sessile macroepifauna in the area include anthozoans (*Renilla mulleri*) crustaceans (*Balanus* spp.) and molluscs (*Crassostrea virginica*).

In a 12-month study conducted by Espy, Houston and Associates (unpublished) in the Trinity-San Jacinto Estuary, annelids were found to be the most prominent phyla (49% of species identified) followed by arthropods (25% of species identified) and Molluscs (20% of species identified). Three remaining phyla (Bryozoa, Rhynchocoela, and Chordata) together comprised 6% of the species identified. Polychaetes (phyla Annelida) dominated the benthic collections at all stations (74% of overall collections), molluscs comprised 15% of overall collections, and arthropods, rhynchocoels, chordates, and bryozoans together comprised 11% of overall collections. The most abundant organism in the benthos was an unidentified polychaete of the family Capitellidae and another capitellid polychaete, *Mediomantus californienses*. Other organisms which constituted at least 30% of the standing crop of a particular collection included *Macoma* spp. (juvenile), an unidentified polychaete, *Amnicola* spp, *Peloscolex* spp, Pelecypod (juvenile), Tanyplinidae, and *Littoridina spinctostoma*.

The benthic invertebrates of the south Texas estuaries comprise a rich and diverse fauna, incorporating Gulf, southern Atlantic, and sub-tropical fauna. In a study of the macrobenthos of the Nueces and Mission-Aransas Estuaries, conducted by Holland et al., annelids were the most prominent phylum (32% of species identified), followed by molluscs and arthropods (each with 29% of species identified). Polychaetes were the most prominent group of organisms numerically, spatially, and temporally. The most abundant polychaete was *Mediomastus californienses*, which was ubiquitous throughout the area. Other polychaetes which were practically ubiquitous included *Streblospio benedicti, Glycinde solitaria*, and *Gyptis vittata*. The second most taxonomically diverse phylum, Mollusca included primarily pelecypods and gastropods. Although diverse, molluscs were not numerically abundant. Among the pelecypods, *Mulinia lateralis, Lyonsia hyalina floridana*, and *Macoma mitchelli* were the most abundant. Gastrapods were never

numerically dominant. Of the arthropods collected, 108 of the 112 taxa were crustaceans. Amphipods and decapods comprised the bulk of the arthropods, both taxonomically and numerically. Only a limited number of copepods, mysids, barnacles, cumaceans, and isopods were collected.

6.2.3 Continental Shelf Communities

Zonation is demonstrated by the shelf macrofauna of central Louisiana (Southwest Research Institute, 1981), and south Texas (Flint and Rabalais, 1981). Biologic factors affecting the distribution and abundance of macrofaunal communities include predation, competition, food availability, physiological tolerance limits, and population characteristics (fecundity, longevity, variability) (Flint and Rabalais, 1981). In the Tuscalusa Trend study, macroinfaunal communities were characterized by substrate habitat and depth and grouped into beach-related habitat (2-4 m), inner shelf habitat (seaward to 20 m), intermediate shelf habitat (20-60 m), and outer shelf habitat. Since the territorial seas of Texas and Louisiana are located in water depths of less than 60 m, the outer shelf habitat is not discussed here.

The shallow beach habitat (2-4 meters) of eastern Louisiana is characterized by well sorted sands and shelf fragments. Macroinfauna species characteristic of this area include the bivalve mollusc, *Donax* spp.; the echinoderm, *Melliter quinquiesperflorata*, and the amphipod *Protohaustorius* spp.

The inner shelf habitat (4-20 meters) includes some of the macroinfaunal species found in estuarine waters as well as other species which are associated with specific substrate types (mud, sandy mud, and sand). The macroinfaunal mud habitat assemblage of the inner shelf is represented by the hemechordate, *Balanoglossus cf. aurantracus*, the polychaete, *Paromphinome* spp. B.; and the molluscs, *Utriculastra canaleculata*, and *Nassarius acutus*. The sandy mud habitat assemblage is represented by the ophiuroids, *Hemipholis elongata* and *Micropholis atra*; the bivalve *Nuculana concentrica*, and the pinnixid crab, *Pinnixa pearsei*. The sand habitat assemblage is represented by the polychaetes, *Nephtys picta* and *Brania wellfleetensis*, the amphipods, *Acanthohaustorius* spp., *Protohaustorius* spp., and *Lepidactylus*, the cephalochordate, *Branchiostoma carribeum*, and the archiannelid, *Polygordius* spp. Transitional macroinfaunal species assemblages are also found which have affinities for a wide range of sediment composition. This group includes the polychaetes, *Magelona cf. phyllisae, Paraprionospio pinnata, Mediomastus californiensis, Sigambra tentaculata, Spiophones bombyx, Myrichele oculata*, and *Owenia fusiformis*; and the mollusc, *Mulinia lateralis*.

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The intermediate shelf macroinfaunal community (20-60 meters) is characterized by the mud habitat assemblage represented by the polychaetes, *Cirrophorus lyribornmis, Nyphtys incesa,* and *Notomastus daueri,* and the sand habitat assemblage represented by the polychaete *Aricidea wassi* and the crustaceans, *Metharpinia floriana, Kalliapseudes* spp. C., and *Ampelisca agassizi.* Macroinfaunal assemblages characteristic of transitional habitats within the intermediate shelf include the polychaetes, *Cossura soyeri, Nereis micromma, Sigambra tentaculata,* and *Aglaophamus verilli.*

The macroepifaunal communities of eastern Louisiana were characterized by regions in the Tuscalusa Trend study. The pro-delta fan assemblage is the area adjacent to the Mississippi Delta in water depths between 4-20 meters. Species of this area of eastern Louisiana occur on bottom sediments of soft mud and in salinities ranging from 30-36 ppt. Predominant species include the sea pansy, *Renilla mulliri,* the molluscs *Nassarius acutus* and *Nuculana concentrica;* the shrimps, *Penaeus aztecus, P. setiferus,* and *Trachypenaeus similus;* and the crabs, *Portunus* spp. and *Callinectes similis.*

The pro-delta sound assemblage is the area of the inshore and nearshore OCS off the coast of the Chandeleur Islands in water depths of 4-20 meters. Species of the pro-delta sound assemblage occur primarily on sediments of soft mud mixed with sand and in salinities ranging from 24 to 36 ppt. This assemblage is populated by such species as the sea pansey, *Renilla mulleri,* the gastropod, *Sinum perspectivum,* the bivalves, *Noctia ponderosa* and *Chione clenchi,* the shrimp, *Penaeus aztecus,* the crabs, *Persephone* spp., *Calappa sulcata,* and *Hepatus epheliticus;* and the echinoderms, *Hemipholis elongates* and *Mellita quinquiesperforata.*

The intermediate shelf assemblage is the area seaward of the pro-delta fan and pro-delta sound assemblages in water depths from 20-60 meters. Species of the intermediate shelf assemblage occur on sediments of muddy sands or sands with bottom salinities of 36 ppt. Representative fauna include gastropods *Strombus* spp., *Murex* spp., *Busycon* spp., and *Fasciolaria* spp.; bivalves *Argopecten* spp., *Tellina* spp., and *Pitar* spp.; shrimps, *Penaeus* spp. and *Secyonia;* crabs *Calappa* spp., *Portunus* spp., *Anasimus* spp., *Libinia* spp., and *Parthenope* spp.; echinoderms, *Encope* spp. and *Stylocidaris;* and starfish *Luidia* spp. and *Astropecten* spp.

The outer shelf and upper slope assemblages are seaward of the intermediate shelf assemblage in water depths between 60-200 meters. The outer shelf and upper slope assemblages occur in areas that are, for the most part, beyond the territorial seas and therefore are not discussed here.

The information which follows concerning the continental shelf macrobenthos of the northwestern Gulf of Mexico and south Texas is taken primarily from a review of the dominant features and processes of the continental shelf environments of the United States (Rabalais et al., 1985) which was presented in a study of the long-term effects of offshore oil and gas activities (Boesch and Rabalais, 1985). The Rabalais study summarizes benthic studies conducted along the Mississippi River Delta and central Louisiana region (Baker et al., 1981), the northwestern Gulf (Harper and McKinney, 1980; Weston and Gaston, 1982; Harper et al., 1981), and the south Texas shelf (Flint and Rabalais, 1981).

Baker et al. (1981) studied the benthic macrofauna in waters 6-98 meters deep around oil and gas platforms on the Louisiana shelf, including an area 320 km west of the Mississippi River delta. The dominant macrobenthos in this study included polychaetes (29% of species and 69% of density), crustaceans (15% of species), and bivalves (7% of individuals). Common species occurring during each collection period of the study were the polychaetes, Paraprionospia, Sigambra, Cossura, Magelona, Nephtys, Lumbrineris, Tharyx, and Nereis. In a study of the inner shelf macrobenthos of southwestern Louisiana, the numerically dominant species included the polychaetes Sabellides, Magelona, Paraprionospio, and Mediomastus; the bivalve, Mulinia; and the phoronid, Phoronis (Weston and Gaston, 1982). In a later study (Gaston, 1985) it was found that seasonal hypoxic events accounted for significant changes in the benthic community structure of this area.

In a study of the inner shelf waters off Galveston, Texas (Harper and McKinney, 1980) the polychaete *Paraprionospio pinnata* was the numerically dominant species. Population fluctuations of *P. pinnata* were found to largely determine the total population density of the region, with the exception of large sets of the bivalves, *Mulinea lateralis* and *Abra aequalis*. Amphipods, like the bivalves, displayed pronounced seasonality, with populations increasing primarily in the spring and again to a lesser degree in the fall. Polychaetes did not exhibit well-defined seasonal fluctuations. Polychaetes also dominate the macrofaunal community in a study of the inner shelf off Freeport, Texas (Harper et al., 1981), however the community is not dominated by any one or a few species. Faunal abundance was found to decrease during July through January and increase through April. The benthos along the shallow Texas shelf has also been occasionally affected by seasonal hypoxia, and changes in the benthic community structure reflect varying responses of taxonomic groups to recovery following hypoxic events (Harper et al., 1981).

In a study of the south Texas shelf (Flint and Rabalais, 1981) polychaetes are the dominant taxa, comprising about 60% of the species. Crustaceans account for 15% of the species and molluscs 12%. The inner shelf of the region (15-30 meters) is characterized by a variable hydrography and poorly-sorted sandy

sediments which provide an unstable habitat in which few species exhibit dominant abundance. Characteristic fauna in the region include the polychaetes, Magelona, Neries, Mediomastus, Aricidea, Paraprionospio, and Prionospio; the bivalve, Tellina; and the amphipod Ampelisca.

6.3 FISH

The following section describes some of the species of fish that occupy the territorial waters of Texas and Louisiana. These species were chosen because of their commercial, recreational, and/or ecological significance.

6.3.1 Spotted Seatrout

Spotted seatrout are restricted mainly to estuaries and emigrate only during periods of environmental extremes or in association with spawning, feeding, and protection from predators (Lorio and Perret, 1980). The importance of estuaries to this species was emphasized by Etzold and Christmas (1979) who pointed out that the spotted seatrout not only spawns in estuaries but is dependent upon them for food throughout its life. The species spawns from spring through early fall in deep channels and depressions in the estuaries (Lorio and Perret, 1980). Larvae move into grassbeds and marshes where growth occurs rapidly. As they develop, they move into deeper portions of the estuary. Adults concentrate in inlets and passes during spring and summer to feed on migrating shrimp and small fish.

6.3.2 Sand Seatrout

A demersal species, the sand seatrout is one of the most abundant fish in the estuaries and continental shelf waters of the Gulf of Mexico (Moffett et al., 1979; Shlossman, 1980; NOAA, 1985). Juveniles and prespawners are found in estuarine and coastal waters, and adults occur generally to the edge of the continental shelf. Spawning takes place from March to September in grounds located in Gulf waters between 15 and 50 meter depths. From spring through fall, juveniles occupy nursery areas located further inshore and in estuaries. Salt marshes may also be used during the early stages of growth. In the late fall, juveniles leave estuarine nursery areas to winter in the open Gulf waters, returning to estuaries in the spring. Adults migrate to spawning grounds in the spring.

6.3.3 Red Drum

The red drum inhabits estuaries and coastal waters out to 22 kilometers at depths up to 50 meters (NOAA, 1985; 1986). Certain adult populations may live exclusively in open waters while others live in bay systems (Simmons and Breuer, 1962). After first spawning, the adults tend to spend more time in Gulf waters and less time in estuaries (NOAA, 1986). Spawning occurs in the fall and winter throughout coastal waters outside of estuaries and in and near barrier island passes to estuaries (Christmas and Waller, 1973; Johnson, 1978; NOAA, 1985). The young fish are carried into the shallow estuaries and tend to associate with seagrasses and marshes (Yokel, 1966; Jannke, 1971; Loman, 1978). Although found in coastal areas throughout the year, the red drum resides in estuaries in the summer and offshore in the winter.

6.3.4 Black Drum

The black drum is most abundant in the northwestern Gulf (particularly in Texas and Louisiana) over a variety of substrates including sand, mud, and oyster reefs (Simmons and Breuer, 1962; Fischer, 1978; FWS, 1978; Silverman, 1979; Benson, 1982; NOAA, 1985). The species inhabits estuarine bays and coastal waters to 50 meters, particularly in areas receiving large river runoffs. Spawning takes place from January to June at the entrance of large sounds, bays, and passes. The adults migrate to passes, spawn, and then return to the preferred bay habitat. Juveniles prefer a muddy, nutrient-rich marsh habitat during their first three months and may frequently inhabit brackish or freshwaters. Most juveniles remain in shallow bay and shore areas until they reach maturity.

6.3.5 Tarpon

Tarpon is a pelagic fish found throughout the nearshore zone of the Gulf of Mexico in waters mostly to depths of 20 meters and rarely to 100 meters (Hildebrand, 1963; Wade and Robins, 1972; McClane, 1974; Smith, 1980; FWS, 1978; NOAA, 1985). Tarpon usually inhabit nearshore areas, estuaries, inlets, passes, and occasionally freshwater rivers. Spawning occurs from May to August in offshore waters. The larvae move inshore, and juveniles are found in nearshore, estuarine, and freshwater areas. As size increases, movement toward ocean waters occurs. Tarpon may also move in and out of estuaries, depending on temperature.

6.3.6 Red Snapper

Red snapper, a demersal fish, is usually found seaward of the 18-meter bottom contour (occasionally up to 1,200 meters) over a variety of surfaces, congregating in depressions or near coral and rock outcrops (Bradley and Bryan, 1974; Fischer, 1978; FWS, 1978; Collins et al., 1980; GMFMC, 1980; Benson, 1982; NOAA, 1985). Individuals generally move inshore in the summer and offshore in the winter. Spawning occurs offshore in water depths from 16 to 37 meters over hard sand and reefs from June to October. Larvae remain in offshore waters near the bottom; juveniles inhabit estuaries and shallow inshore areas, beaches, and channels. As juveniles mature, they move into deeper waters.

6.3.7 Spanish and King Mackerel

The Spanish and king mackerels are migratory pelagic species found in estuaries and coastal waters to depths of 100 to 200 meters (NOAA, 1985). Large schools are known to pass near the beach during seasonal migrations (GMSAFMC, 1985) and may enter tidal estuaries, bays, and lagoons (Berrien and Finan, 1977). Apparently, seasonal north/south migrations of Spanish mackerel occur along the south Texas coast (GMSAFMC, 1985). Populations of king mackerel concentrate off the Texas coast in summer and off Louisiana in winter indicating that these areas may be significant spawning sites (McEachran et al., 1980; GMSAFMC, 1985; Godcharles and Murphy, 1986). Mackerel spawn from spring to fall in shallow waters, usually less than 20 meters deep (McEachran et al., 1980; NOAA, 1985; Godcharles and Murphy, 1986). Mackerel seldom enter brackish waters (NOAA, 1985). Some juveniles use estuaries as nursery grounds, but most stay nearshore in open beach waters (Kelly, 1965).

6.3.8 Gulf Menhaden

Gulf menhaden are found only in the Gulf of Mexico and is most abundant off Louisiana and Mississippi (Lassuy, 1983b). Adults primarily inhabit the open waters of the Gulf, concentrating nearshore during spring and summer and moving offshore during fall and winter (Roithmayr and Waller, 1983; Chapoten, 1974). Spawning occurs from the fall to spring in marine waters between eight and 80 meters (Christmas et al., 1982; NOAA, 1985). Larvae move to estuarine waters where transition to the juvenile stage occurs. Juveniles move into shallow bayous of marshes where they feed and receive protection from predators. As juveniles grow, they move to deeper, more saline waters of the open bays, sounds, and nearshore marine waters (Etzold and Christmas, 1979). Some first year juveniles may overwinter in estuaries (Kroger and Pristas, 1974). Movement of adults and maturing juveniles from estuaries to open waters occurs

from mid-summer through winter (Lassuy, 1983b), and movement back to nearshore waters occurs early the following spring (Lewis and Roithmayr, 1981).

6.3.9 Atlantic Croaker

Atlantic croaker are demersal bony fishes found in estuarine and coastal waters out to about 120 meters in depth.[*] The species is estuarine-dependent; all life stages are known to occur in abundance in estuarine waters (Lassuy, 1983a). The species is common along the entire Gulf coast, but is most abundant off Louisiana and Mississippi (Lassuy, 1983a). When inshore temperatures are high in late spring to early fall, heavy concentrations of croakers are found inside the 20 meter depth, and when inshore temperatures drop, populations move offshore (GMFMC, 1980). Croakers appear to spawn during fall and winter from open waters near passes and channel entrances to estuaries in water depths up to 20 meters (Juhl et al., 1975; White and Chittenden, 1977; Warren et al., 1978; NOAA, 1985). Larvae are first pelagic and soon become demersal, moving into estuarine nursery grounds where transition to the juvenile stage occurs (Fruge and Truesdale, 1978; Diaz and Onuf, 1985). Young croakers remain in estuaries at least through spring or early summer before migrating to open waters (Lassuy, 1983a).

6.3.10 Southern Flounder

The southern flounder is a demersal species that is most abundant in the western Gulf of Mexico in water depths up to 60 meters. Adults spend most of the year in bays and estuaries and migrate to deeper offshore waters during the fall and winter when inshore water temperatures drop. Spawning occurs offshore (beyond 30 meters) from fall to spring (Stokes, 1977). Larvae are carried by winds and currents into estuarine nursery grounds (Gilbert, 1986). Juveniles remain in estuaries until reaching sexual maturity (about two years) (Stokes, 1977; Nall, 1979; Manooch, 1984), and do not move offshore until just prior to spawning (Powell and Schwartz, 1977). After spawning, adults return to coastal bays and estuaries where they remain until the following spawning season.

6.3.11 Gulf Flounder

The gulf flounder, a demersal fish, is abundant from southern Florida to Atchafalaya, Louisiana in nearshore waters to 150 meters. They rarely occur west of that point. (Topp and Hoff, 1972; Stokes, 1977; Nall, 1979; Benson, 1982; NOAA, 1985). Adults favor bays and the nearshore zone to 30 meters during summer months, and leave their estuaries for offshore areas to spawn during fall and winter. In spring,

larvae and early juveniles move into estuaries which serve as nursery areas during the spring, summer, and fall. Juveniles concentrate in estuaries and shallow nearshore coastal waters.

6.3.12 Cobia

The cobia is a large pelagic and epibenthic species that is found year-round throughout the coastal waters of the Gulf of Mexico near floating objects, wrecks, reefs, pilings, and buoys, and occasionally in estuaries. The species is most abundant in 40 meters of depth in the northern and western Gulf and appears in Texas waters in March and April. The only known spawning areas are in the northern Gulf where the spawning occurs during the spring and summer, except in bays and estuaries. Nursery areas include river mouths, bays, and coastal areas.

6.3.13 Gulf Butterfish

The gulf butterfish, a demersal species, is found along the entire Gulf coast both in brackish and oceanic waters within depths of about 160 meters (Murphy, 1981; NOAA, 1985). Spawning occurs during the spring, summer, and fall with two peak periods from February to early May and September to November. Spawning grounds are offshore; nursery areas are inshore. As juveniles mature, they move offshore congregating in waters 30 to 100 meters deep. Butterfish also display seasonal inshore-offshore movements, retreating to deeper, warmer waters during the winter.

6.4 MARINE MAMMALS

Twenty-eight species of marine mammals are known from sightings and/or strandings to occur in or migrate through the Northern Gulf of Mexico (Schmidly, 1981). Cetaceans (whales, dolphins, and porpoises) are the most common. One sirenian, the West Indian Manatee, is found at least peripherally in Texas and Louisiana waters. One pinniped, the California sea lion, has been introduced and occurs in small numbers only in the feral condition. All marine mammals are protected under the Marine Mammal Protection Act of 1972.

Few marine mammals commonly occur in the inshore waters. Within the study area, only the West Indian Manatee, right and sperm whales, and bottlenose and striped dolphin are regularly observed (MMS, 1983 and Fritts et al., 1983). Bottlenose dolphin are notably the most common, occurring in bays, inland waterways, ship channels and nearshore waters.

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The Cetaceans found in the Gulf include species which occur in most major oceans and which, for the most part, are eurythermic with a broad range of temperature tolerances (Schmidly 1981). These include the sei, fin, blue, humpback, sperm, goosebeaked, false killer and killer whales, grampus, and saddleback whales, and the Atlantic bottlenose and striped dolphin. Nine cetaceans may be considered warm-stenotherms with distributions centered in tropical warm-temperature waters (Schmidly, 1981). These are the Bryde's, pygmy sperm, dwarf sperm, Blainville's beaked, pygmy killer and short-finned pilot whales and the rough-toothed, bridled, and spinner dolphins. The right and minke whales have distinct bipolar distributions and are regarded as cold-stenothermal (Schmidly, 1981).

6.4.1 Right Whale

The right whale is considered endangered by the U.S. Fish and Wildlife Service. In the western North Atlantic, right whales are distributed from Iceland to Florida and the Gulf of Mexico. The whales migrate northward along the eastern Florida coast between January and March and have been observed in the Gulf of Mexico during this time. The southward migration occurs in fall farther offshore. Mating takes place in the North Atlantic in late summer. Gestation is assumed to be about one year with calves suckling for about a year. Right whales feed by "skimming" at or below the surface for copepods and euphasids. No right whales were observed during 1980-1981 aerial surveys (Fritts et al., 1983).

6.4.2 Blue Whale

Blue whales are the largest living mammals and are considered endangered with only approximately 12,000 individuals remaining (Schmidley, 1981). Only two records of blue whales are recorded in the Gulf, one along the Texas coast in 1940 and the other in Louisiana in 1924. During spring and summer, blue whales feed in northern waters. Feeding is relatively shallow and almost exclusively on brill. In fall and winter they move south into temperate and perhaps tropical waters. Blue whales usually occur singly or in pairs. No blue whales were sighted in the 1980-1981 aerial surveys of the northern Gulf (Fritts et al., 1983).

6.4.3 Sei Whale

Sei whales occur in all oceans, and are considered endangered. Sei whales are widely distributed in the nearshore and offshore waters of the western North Atlantic but are rare, in tropical and polar areas. Records for the Gulf of Mexico are limited to strandings from Campeche, Mexico, and from the coasts of Mississippi and Louisiana. Little information is available on their seasonal movements. Their diet consists

primarily of copepods, krill, and small schooling fish. Sei whales usually travel in groups of two to five individuals, but may concentrate in larger numbers at their feeding grounds.

6.4.4 Fin Whale

Fin whales are considered endangered by the Fish and Wildlife Service. In the western North Atlantic they occur from Greenland south to the Gulf of Mexico and the Caribbean. Fin whales have stranded in all regions of the Gulf. Sightings have been recorded in the Gulf throughout the year and suggest a somewhat isolated population. Their diet consists of brill, squid, and small fish.

6.4.5 Minke Whale

Minke wales are the smallest baleen whales in the Northern Hemisphere. In the western North Atlantic they occur from the ice pack south to the West Indies and the Gulf of Mexico (Leatherwood and Platter, 1975). They have a general north-south and onshore-offshore trend between summer and winter. Evidence suggests minkes winter offshore and south of Florida and the Lesser Antilles, and summer north of Cape Cod. Minke whales are more solitary than other species of baleen whales. Pairing occurs from October to March, gestation is about 10 months and lactation is estimated to be less than 6 months. Diet consists of euphasids and small fish (Lowery, 1974).

6.4.6 Sperm Whale

Sperm whales are listed as endangered. They occur in all of the world's oceans along the edge of the continental shelf, but rarely on the shelf itself, being basically limited to deeper waters. In the past they were numerous enough in the Gulf of Mexico to justify full-scale whaling operations. This and relatively common sitings (Fritts et al., 1983) suggest there may be a separate population in the Gulf. In spring bull sperm whales join female nursery schools and form "harems". Mating occurs in spring during migration north. Gestation lasts 14 to 16 months with a 1 to 2 year lactation period. Diet consists primarily of squid but includes many other deepwater species and bottom dwellers.

6.4.7 Pygmy Sperm Whale

Pygmy sperm whales have a worldwide distribution in warmer seas and to be relatively rare. These small whales strand frequently throughout the eastern and northern Gulf of Mexico. Sightings are rare in

the Central Gulf and more common in the Western Gulf. Mating takes place in late summer and there is a gestation period of nine months. Diet consists of squid, crab, shrimp and some fishes. Pygmy sperm whales appear to occur in small schools of three to six individuals.

6.4.8 Dwarf Sperm Whale

Dwarf sperm whales are very similar in appearance to pygmy sperm whales. Their range, habitat requirements, and diet are very similar, but dwarf sperm whales have been reported more frequently from the Atlantic coast than from the Gulf coast.

6.4.9 Antillean Beaked Whale

In the Western North Atlantic the Antillean beaked whale occurs from New York south to Trinidad and the Gulf of Mexico. They are rare in the Gulf, known only from five records, three from Texas and two from Florida. They may inhabit deep waters close to shorelines. Their seasonal moments are not known. Diet consists primarily of squid (Lowery, 1974).

6.4.10 Short-Finned Pilot Whale

Short-finned pilot whales occur in the tropical and warm temperate regions of the Atlantic, Indian, and Pacific Oceans. Their range in the western North Atlantic extends south from Virginia to northern South America and includes the Gulf of Mexico. These whales normally live in deep waters from the continental shelf seaward though they have been sighted in both the Corpus Christi and Brownsville Texas areas (Schmidly, 1981). They have an extended breeding and calving season. The gestation period is about 1 year. Diet consists of squid and fish. Short-finned pilot whales are known to occur in groups of 60 or more, but smaller groups are more common (Leatherwood and Platter, 1975).

6.4.11 Bottlenose Dolphin

The bottlenose dolphin is the most common cetacean in the Gulf of Mexico. They occur in bays, inland waterways, ship channels, and nearshore waters. Apparently, there are two groups of bottlenose dolphins--small discrete populations that inhabit coastal areas and offshore populations that congregate in large groups. Surveys of the Louisiana-Mississippi coastal waters report about 2,000-6,000 bottlenose dolphins (Leatherwood and Platter, 1975). Aerial surveys offshore Marsh Island, Louisiana, indicate about 1

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dolphin/1.4 mi^2 (1 dolphin/3.7 km^2; Fritts et al., 1983). Surveys offshore Texas report about 1,000-5,000 dolphins (Orr, 1977). Aerial surveys indicate about 1 dolphin/1.9 mi^2 (0.203 dolphins/4.9 km^2) offshore Brownsville, Texas (Fritts et al., 1983). Dolphins usually occur in herds of 3-7 animals, but large herds of 200-600 dolphins have been observed. Calving and mating occurs from February to May. Gestation lasts approximately 12 months and lactation up to 18 months. The calving interval is two to three years.

Bottlenose dolphins feed on a variety of fishes, mollusks, and arthropods, apparently taking whichever prey species is most abundant. Leatherwood and Platter (1975) recorded seven recurrent feeding patterns in the northern Gulf: (1) foraging behind working shrimp boats and eating organisms disturbed by the nets; (2) feeding on trashfish dumped from the decks of shrimp boats; (3) feeding on fish attracted to nonworking shrimpers; (4) herding schools of fish by encircling and charging the school or feeding on the stragglers; (5) sweeping schools of small bait fish into shallow water ahead of a line of dolphins and charging into the school or feeding on stragglers; (6) crowding small fish into shoals or mud banks at the base of grass flats, driving fish completely out of the water and then sliding onto banks to retrieve them; and (7) individual feeding.

6.4.12 Striped Dolphin

The striped dolphin is found widely throughout temperate and tropical waters of the world. In the western North Atlantic they prefer warmer, offshore waters and normally are confined to the Gulf Stream or continental slope (Leatherwood and Platter, 1975). With one exception, all records from the Gulf of Mexico are from summer and fall. This may be the result of seasonal movements of the striped dolphin in and out of the Gulf. Diet consists of squid and small fish.

6.4.13 West Indian Manatee

The West Indian Manatee is listed as endangered, with U.S. populations estimated to be from 750 to over 1000 individuals. The U.S. population is centered in coastal Florida, but records exist from as far as New Jersey on the Atlantic coast and Louisiana and Mississippi on the Gulf coast. Infrequent Texas sightings are probably strays from a Mexican population. Manatees are found in both fresh and salt water and may be sighted in canals, sluggish rivers, estuaries, and saltwater bays. Individuals are also found as far as 6 km off the coast of Florida in the Gulf of Mexico. Manatees are herbivorous and prefer shallow water where they consume almost any vegetation available. Manatee calves are born throughout the year and nursed in the water. The reproductive rate for the species is one calf per adult female every 2 to 2.5 years.

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7. COMMERCIAL AND RECREATIONAL FISHERIES HARVESTS

7.1 OVERVIEW

In 1985 and 1986, the Gulf of Mexico led all other regions of the country in pounds of commercial fish landed (39% of total U.S. landings in both years) and was second to the Pacific and Alaska region in the value of the catch landed (26% of the total value of U.S. catch in 1985 and 28% of the total value of U.S. catch in 1986). Commercial fish landings in Louisiana during 1987 were 1.8 billion pounds valued at $316 million and landings in Texas during the same time were 111 million pounds valued at $200 million (NMFS, 1988).

The principal Louisiana fishery in terms of value is the shrimp fishery (brown and white), and in terms of landings, the menhaden fishery. The oyster and blue crab fisheries rank third and fourth in value, respectively, following the shrimp and menhaden fisheries (MMS, 1982a). Other important food finfish landed in Louisiana include red drum, black drum, flounder, Atlantic sheepshead, spotted seatrout, red snapper, and swordfish.

In Texas, the production of shellfish overwhelms all other commercial fisheries in both sales and volume. Shrimp (brown and white) have consistently accounted for 75% of the landings and 95% of the landings value for Texas (Restrepo and Associates, 1982). Shrimp ranks first in landings and value. Blue crabs and oysters rank second and third in landings, respectively, and are similar in value (MMS, 1982a). Major commercial finfish species in Texas include spotted seatrout, black drum, flounder, cobia, pompano, sheepshead, and red snapper.

In 1985, Texas ranked second behind Florida among the Gulf states in the estimated total number of fish caught by recreational fishermen. Louisiana ranked third. Over 45% of the total marine recreational catch in Louisiana and Texas consisted of various members of the Sciaenidae family (i.e., drum, seatrout, croaker) (NMFS, 1986a). Excluding the catfish, which although frequently caught by sport fishermen is generally considered a nuisance species, the spotted seatrout was the most commonly caught sport fish in Louisiana and Texas. The Atlantic croaker was the next most commonly caught species followed by the red

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drum and sand seatrout. The spotted seatrout and red drum were the most highly sought recreational species (NMFS, 1986a).

The sections that follow briefly discuss the distribution and relative abundance of the most important commercial and recreational species in Louisiana and Texas. The relative commercial and recreational importance of each species is also discussed.

7.2   SHELLFISHERIES

7.2.1 Brown and White Shrimp

The brown shrimp is an estuarine-dependent demersal species found throughout the Gulf of Mexico, with a maximum density along the Texas-Louisiana coast. It is found from the shore to depths of 110 meters, but is most common on mud or sandy mud substrates between 30 and 55 meters deep (NOAA, 1985). The brown shrimp is the major contributor to the Gulf of Mexico shrimp fishery, which is the most valuable fishery in the United States. Brown shrimp fishery activities are concentrated inside the 55 meter contour, but extend to at least 90 meters in depth.

Like the brown shrimp, the white shrimp is an estuarine-dependent demersal species that inhabits the Gulf of Mexico coast from Apalachee Bay, Florida to Ciudad, Mexico, with a center of abundance in Louisiana waters. It is plentiful in waters where the continental shelf is broad and shallow from the shore to 65 meters, but rarely occurs at greater depths (NOAA, 1985). Although brown shrimp constitutes the largest portion of the Gulf shrimp fishery, the white shrimp is highly valued for human food.

Louisiana led all Gulf states in landings of shrimp in 1986 with 146.7 million pounds. Texas landings were second with 97.5 million pounds (NMFS, 1987). There is also a commercial bait-fishery element of the Texas shrimp fishing industry. In 1978, it was estimated that about 2.3 million pounds of dead and live bait shrimp were taken in Texas waters with a value of $6.8 million (Liebow et al., 1980).

7.2.2 American Oyster

The American oyster is a bivalve mollusk found throughout the Gulf of Mexico in estuaries, shallow nearshore waters, and on reefs located near river mouths (NOAA, 1985). Most concentrations are found in depths of 10 meters or less. The American oyster supports an important commercial fishery in the Gulf of

Mexico. The fishery for this species is the fourth largest in the U.S. Gulf of Mexico (behind shrimp, menhaden, and blue crab), and the species is also harvested recreationally. Landings of oysters in the Gulf of Mexico account for approximately one third of the total U.S. landings. Louisiana has the largest shell fisheries for oysters in the Gulf of Mexico, with 58% of the total for the region in 1986 (NMFS, 1987).

7.2.3 Blue Crab

The blue crab is a decapod crustacean found throughout the Gulf of Mexico, from Florida to the Yucatan Peninsula. It inhabits estuaries and the nearshore to depths of about 90 meters, but is most common in waters 35 meters deep or less. The species generally favors muddy and sandy bottoms in shallow waters with some vegetation (NOAA, 1985). The commercial blue crab fishery has become increasingly important and is one of the largest in volume in the Gulf of Mexico, with 55.5 million pounds harvested in 1986 (NMFS, 1987). Louisiana is the largest commercial producer of blue crabs in the Gulf of Mexico. There is also a substantial recreational fishery for blue crab in the Gulf. The sport fishery is thought to contribute significantly to the total catch of blue crabs, although estimates of recreational fishing vary widely. In Galveston Bay, Texas it has been estimated that the recreational catch was almost 6% of the commercial harvest from that area (Benefield, 1968), while in Louisiana sport fishery landings have been estimated to exceed commercial landings by nearly four times (Lindall and Hall, 1970).

7.3 FINFISHERIES

7.3.1 Gulf Menhaden

The gulf menhaden is a nearshore marine and estuarine pelagic species found throughout the Gulf of Mexico, with centers of abundance off Louisiana and Mississippi (Lassuy, 1983b). It inhabits estuarine and shelf waters to depths of 120 meters (NOAA, 1985). The gulf menhaden supports the largest single fishery by weight in the U.S., providing over one-quarter of the nation's commercial fishery landings (Lassuy, 1983b). Fishing grounds extend discontinuously from Apalachee Bay, Florida to Matagorda Bay, Texas with most catches landed in Louisiana and Mississippi.

7.3.2 Red Snapper

The red snapper is a demersal fish found throughout the Gulf of Mexico, with centers of abundance in U.S. waters in the southern Gulf and west Florida. The species is found over sandy and rocky bottoms,

around reefs and underwater objects at depths from the shore line to 200 meters, and possibly beyond 1,200 meters. Juveniles inhabit shallow nearshore and estuarine waters and are most abundant over sand or mud bottoms (NOAA, 1985). The red snapper dominates commercial landings and value of landings for Gulf of Mexico reef fish. The species is also a highly esteemed recreational sport fish, primarily in the northern Gulf and Florida.

7.3.3 Atlantic Croaker

The Atlantic croaker is an estuarine-dependent demersal fish that is common throughout the Gulf of Mexico, with centers of abundance off Louisiana and Mississippi (Lassuy, 1983a). It is usually found over mud and sandy/mud bottoms in coastal waters out to about 120 meters (NOAA, 1985). The Atlantic croaker is subject to significant commercial and sport fisheries in the Gulf of Mexico. Major commercial harvesting areas are located between Mobile Bay, Alabama and Lake Calcasieu, Louisiana. Less important fishery grounds are located throughout the northern Gulf (NOAA, 1985). The croaker is also a frequently caught sport fish, second only to catfish in Texas and third in Louisiana behind catfish and spotted seatrout (NMFS, 1986a). However, it is a less preferred sport fish than the spotted seatrout, black drum, and red drum.

7.3.4 Red Drum

The red drum is an estuarine-dependent demersal species that occurs in the Gulf of Mexico from southwest Florida into northern Mexico, with centers of concentration in the northern Gulf. The red drum is found over a variety of substrates including sand, mud, and oyster reefs. It occurs in estuaries and nearshore waters to depths of 40 meters (NOAA, 1985). The red drum is commercially harvested in the northern Gulf off the coast of Louisiana and Mississippi and, to a lesser extent, in western Florida and Alabama (NOAA, 1985). The commercial sale of red drum in Texas has been prohibited since 1981 and catch limitations also exist in Florida. Red drum is a highly prized recreational fish in the Gulf of Mexico. In 1985, Louisiana led the Gulf states in average annual recreational catch of red drum in both number and weight. Texas ranked third among the Gulf states.

7.3.5 Black Drum

The black drum is a demersal, estuarine-dependent species distributed throughout the Gulf of Mexico. It is most abundant in coastal and estuarine areas off the coasts of Texas and Louisiana to water depths of

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50 meters. It is found over a variety of substrates including sand, mud, and oyster beds. The species is most commonly found in areas receiving large river runoffs (NOAA, 1985). The black drum is a valuable recreational and commercial species with most of the U.S. commercial harvest occurring in the Gulf of Mexico (Sutter et al., 1986). The major commercial fishing area in the Gulf is in the northwest off the Mississippi Delta. The sport catch for black drum in the Gulf of Mexico is much greater than commercial landings (Silverman, 1979), with most recreational black drum fishing taking place in Texas (NOAA, 1985).

7.3.6 Spotted Seatrout

The spotted seatrout is a demersal species that is common along the entire Gulf of Mexico coast, with centers of abundance off eastern Louisiana, south Texas, Mississippi and Alabama (Lassuy, 1983c). It is found in estuaries and coastal waters out to 20 meters in depth and is often associated with sand flats, seagrass beds, salt marshes, and tidal pools of higher salinity (NOAA, 1985). The spotted seatrout supports valuable commercial and sport fisheries throughout the coastal Gulf of Mexico and it is one of the most frequently caught recreational fish in Texas and Louisiana, second only to catfish (NMFS, 1986a). The estimated sport catch of spotted seatrout as a whole is substantially greater than the commercial catch (NMFS, 1981).

7.3.7 Sand Seatrout

The sand seatrout is a demersal fish found in the coastal and shelf waters of the Gulf of Mexico. It is one of the most abundant fish in estuaries and in the shelf waters of the Gulf, usually inhabiting sandy and muddy bottoms out to the edge of the continental shelf (NOAA, 1985). Commercial fishing for sand seatrout is concentrated along the coasts of Florida, Mississippi, and Louisiana. The sand seatrout is also fished recreationally throughout its range.

7.3.8 Spanish Mackerel

The Spanish mackerel is a pelagic species that occurs throughout the coastal zone of the Gulf of Mexico. It is found in estuaries and on the continental shelf out to depths of 100 meters (NOAA, 1985). They are concentrated in the northern Gulf of Mexico from Texas to northwest Florida in the summer and off southern Florida and Louisiana in the winter (Godcharles and Murphy, 1986). The Spanish mackerel is harvested commercially, primarily from south Florida to Louisiana, and is harvested recreationally throughout

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its range. On the Gulf coast, the sport catch of Spanish mackerel has been estimated to be 50% higher than the commercial catch (GMSAFMC, 1982).

7.3.9 Gulf and Southern Flounder

The gulf flounder is a demersal species that occurs from southern Florida to Corpus Christi, Texas and is most common in the eastern half of the Gulf (Gilbert, 1986). It is found in nearshore waters out to 150 meters over hard, sandy bottoms. Adults favor bays and the nearshore zone during summer months, while juveniles concentrate in estuarine and shallow, nearshore areas (NOAA, 1985).

The southern flounder is a demersal species that occurs in the Gulf of Mexico from the Caloosahatchee estuary in Florida to northern Mexico and is most common in the western half of the Gulf. It inhabits coastal waters to depths of 60 meters, including estuaries and rivers, and is usually associated with muddy and sandy bottoms (NOAA, 1985).

The gulf and southern flounders are two of the three species making up the general flatfish commercial fishery. They are combined in commercial catch statistics with the summer flounder, so the exact importance of each species cannot be determined. It does not appear that any one Gulf state is dominant in the number of pounds of commercial "flounder" harvested. The number of flounder caught recreationally are well below those for many other species in the Gulf. More recreational flounder were taken in Texas waters than all of the other Gulf states together (NMFS, 1986a). Recreational catch of southern flounder in the Gulf appears to be much greater than that of the gulf flounder, with the greatest numbers caught in Texas and Louisiana (NMFS, 1986a).

8. COASTAL ZONE MANAGEMENT AND SPECIAL AQUATIC SITES

8.1 REQUIREMENTS OF COASTAL ZONE MANAGEMENT ACT

The Coastal Zone Management Act requires that states make consistency determinations for any federally licensed or permitted activity affecting the coastal zone of a state with an approved coastal zone management program (CZMP; 16 USC Sec. 1456[c][A] Subpart D). Under the Act, applicants for federal licenses and permits must submit a certification that the proposed activity complies with the state's approved CZMP and will be conducted in a manner consistent with the CZMP. The state then has the responsibility to either concur with or object to the consistency determination. For NPDES general permits, EPA is considered an applicant submitting the general permit to the state for a consistency determination.

Consistency certifications are required to include the following information (15 CFR 930.58):

- A detailed description of the proposed activity and its associated facilities;

- A brief assessment relating the probable coastal zone effects of the proposal and its associated facilities to relevant elements of the CZMP;

- A brief set of findings indicating that the proposed activity, its associated facilities, and their effects are consistent with relevant provisions of the CZMP; and

- Any other information required by the state.

Discharges covered by the OCS general permit will occur in Federal waters outside the boundaries of the coastal zone which extends to the 3-mile territorial sea limit. However, because these discharges could affect territorial seas or coastal waters, a consistency assessment for the general permit has been prepared and submitted to the State of Louisiana for approval. Texas does not have a Federally-approved CZMP. A description of the coastal zone management planning status for Louisiana and Texas follows.

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8.2 STATUS OF COASTAL ZONE MANAGEMENT PLANNING

8.2.1 Louisiana

The State of Louisiana has a Federally-approved coastal zone management program. The basis for the Louisiana Coastal Resources Program (LCRP) is Act 361 of the State and Local Coastal Resources Management Act of 1978 (La. R.S. 49:213.1). The Act implements a set of state coastal policies (Section 213.2) and coastal use guidelines (Section 213.8) that apply to coastal land and water use decisionmaking. A number of existing state regulations are also incorporated into the program, including those that address: (a) oil, gas, and mineral operations; (b) management of wildlife, fish, and other aquatic life; (c) management of oyster bedding grounds; (d) water quality; (e) resident endangered or threatened species; and (f) construction and operation of offshore terminal facilities. Where appropriate and applicable, requirements under these existing state regulatory measures have been incorporated into the coastal use guidelines. The LCRP indicates that aside from the coastal use guidelines, existing state water and air quality provisions (La. R.S. 30:1068, 1081-1087, 1091-1096, 38:216) are applicable to the possible direct effects and associated or non-associated facilities connected with oil and gas activities.

The coastal use guidelines are based on seven general policies outlined in Act 361. The coastal use guidelines are implemented through coastal use permits and in-lieu permits and are the criteria for granting or denying coastal use permits. In-lieu permits provide for the use of permit requirements that existed before the Act took effect. In-lieu permits fulfill the role of coastal use permits, thereby avoiding duplicative permitting procedures.

Four regional planning councils are involved with the coastal area of Louisiana. The councils act in an advisory capacity to local units of government, state agencies, and local groups.

8.2.2 Texas

In May 1981, the State of Texas formally withdrew from the Federally-sponsored coastal zone management program. In place of a coastal zone management plan with certain mandated features of the Coastal Zone Management Act, Texas has a network of state agencies that have the responsibility of managing coastal resources. These agencies include the Air Control Board, Parks and Wildlife, the Department of Water Resources, the Health Department (marine life), the General Land Office (environmental protection), and the Railroad Commission (oil and gas activity regulation).

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This network is held together by a memorandum of understanding (MOU) between the state agencies. The MOU exists to accomplish the following:

(a)   Improve coordination between state agencies;

(b)   Require state agencies to collect data and conduct impact assessments in order to approve, deny, or conditionally approve proposed projects; and

(c)   Encourage state agencies to participate on a voluntary basis so as to avoid a duplication of effort, overlaps, and conflicts between agencies.

The General Land Office, operating under authority vested in an elected commissioner by the Texas Coastal Public Land Management Act of 1973, coordinates the permitting system conducted by the state. The General Land Office reviews and recommends actions to be taken based on permit applications received from the U.S. Army Corps of Engineers and Texas state agencies that have statutory permitting authority. The area of jurisdiction for this managing network is public land/waters under tidal effect including bays, rivers, and the Gulf of Mexico out to the three league line. Most of the activities reviewed concern oil and gas development, dredging, and spoil areas.

Five regional planning units are operating in the Texas coastal area. These Councils of Government provide technical assistance to their member cities and states. In the face of limited regulatory powers, the Councils of Government have a limited impact on coastal resource management.

Since no formal coastal zone management program (in the context of the Coastal Zone Management Act) exists in Texas, no formal policies associated with a program may be cited. Policies and permitting procedures have been established to implement coastal resources management on an agency-by-agency basis, and a voluntary coordination mechanism is in operation by the General Land Office.

8.3 CONSISTENCY ASSESSMENT

Policies and guidelines of the Louisiana Coastal Resource Program that are potentially relevant to discharges from offshore oil and gas exploration, development, and production are set forth in various sections of Act 361. The seven policies stated in Section 213.2 of Act 361 intend:

(1)   To protect, develop, and where feasible, restore or enhance the resources of the state's coastal zone;

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(2)   (a) To assure that, to the maximum extent feasible, constitutional and statutory authorities
        affecting uses of the coastal zone should be included within the Louisiana Coastal Resources
        Program and that guidelines and regulations adopted pursuant thereto shall not be interpreted to
        allow expansion of governmental authority beyond those laws;

        (b) To express certain regulatory and non-regulatory policies for the coastal zone management
        program. Regulatory policies are to form a basis for administrative decisions to approve or
        disapprove activities only to the extent that such policies are contained in the statutes of this
        state or regulations duly adopted and promulgated pursuant thereto. They are to be applicable
        to each governmental body only to the extent each governmental body has jurisdiction and
        authority to enforce such policies. Other policies are nonregulatory. They are included in the
        Coastal Zone Management Plan to help set out priorities in administrative decisions and to
        inform the public and decision makers of a coherent state framework, but such policies are not
        binding on private parties;

(3)   To support and encourage multiple use of coastal resources consistent with the maintenance and
        enhancement of renewable resource management and productivity, the need to provide for
        adequate economic growth and development and the minimization of adverse effects of one
        resource use upon another, without imposing any undue restriction on any user;

(4)   To employ procedures and practices that resolve conflicts among competing uses within the
        coastal zone in accordance with the purpose of this Part and simplify administrative procedures;

(5)   To develop and implement a coastal resources management program which is based on
        consideration of our resources, the environment, the needs of the people of the state, the nation,
        and of state and local government;

(6)   To enhance opportunities for the use and enjoyment of the recreational values of the coastal
        zone; and

(7)   To develop and implement a reasonable and equitable coastal resources management program
        with sufficient expertise, technical proficiency, and legal authority to enable Louisiana to
        determine the future course of development and conservation of the coastal zone and to ensure
        that state and local governments have the primary authority for managing coastal resources.

In order to provide additional guidance for developing coastal use guidelines, the Louisiana legislature
established twelve goals in Section 213.8(c) of Act 361, two of which state that the guidelines will:

•   Require careful consideration of the impacts of uses on water flow, circulation, quantity, and
    quality and require that the discharge or release of any pollutant or toxic material into the water
    or air of the coastal zone be within all applicable limits established by law, or by federal, state,
    or local regulatory authority; and

•   Establish procedures and criteria to ensure that appropriate consideration is given to uses of
    regional, state, or national importance energy facility siting and the national interests in coastal
    resources.

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The guidelines have been written to implement the policies (Section 213.2) and goals (Section 213.8(C)) of Act 361. The legislative guidance contained in Act 361 requires decision-making criteria that will protect, develop, and where feasible, restore the natural resources of the state while providing for adequate economic growth and development. In order to accomplish these sometimes conflicting goals, the guidelines are organized as a set of performance standards for evaluating projects or proposals on their individual merits for compliance with the guidelines. This "performance standards" approach deals primarily with the impacts of a proposed action on coastal resources. Under this approach, policies need not be developed for all aspects of a use but only for those which would have direct and significant impacts on coastal waters.

The pertinent guidelines for oil and gas discharges in waters of the Louisiana OCS are the Guidelines for Disposal of Wastes and the Guidelines for Oil, Gas, and Other Mineral Activities. These guidelines state the following:

Guidelines for Disposal of Wastes

Guideline 8.1. The location and operation of waste storage, treatment, and disposal facilities shall be avoided in wetlands to the maximum extent practicable, and best practical techniques shall be used to minimize adverse impacts which may result from such use.

Guideline 8.2. The generation, transportation, treatment, storage, and disposal of hazardous wastes shall be pursuant to the substantive requirements of the Department of Natural Resources adopted pursuant to Act 334 of 1978 and approved pursuant to the Resource Conservation and Recovery Act of 1976 P.L. 94-580, and of the Office of Conservation for injection below surface.

Guideline 8.3. Waste facilities located in wetlands shall be designed and built to withstand all expectable adverse conditions without releasing pollutants.

Guideline 8.4. Waste facilities shall be designed and constructed using best practical techniques to prevent leaching, control leachate production, and prevent the movement of leachate away from the facility.

Guideline 8.5. The use of overland flow systems for non-toxic, biodegradable wastes, and the use of sump lagoons and reservoirs utilizing aquatic vegetation to remove pollutants and nutrients shall be encouraged.

Guideline 8.6. All waste disposal sites shall be marked and, to the maximum extent practicable, all components of waste shall be identified.

Guideline 8.7. Wastes facilities in wetlands with identifiable pollution problems that are not feasible and practical to correct shall be closed and either removed or sealed, and shall be properly revegetated using the best practical techniques.

Guideline 8.8. Waste shall be disposed of only at approved disposal sites.

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Guideline 8.9. Radioactive wastes shall not be temporarily or permanently disposed of in the coastal zone.

Guidelines for Oil, Gas, and Other Mineral Activities

Guideline 10.1. Geophysical surveying shall utilize the best practical techniques to minimize disturbance or damage to wetlands, fish and wildlife, and other coastal resources.

Guideline 10.2. To the maximum extent practicable, the number of mineral exploration and production sites in wetland areas requiring floatation access shall be held to the minimum number, consistent with good recovery and conservation practices and the need for energy development, by directional drilling, multiple use of existing access canals, and other practical techniques.

Guideline 10.3. Exploration, production, and refining activities shall, to the maximum extent practicable, be located away from critical wildlife areas and vegetation areas. Mineral operations in wildlife preserves and management areas shall be conducted in strict accordance with the requirements of the wildlife management body.

Guideline 10.4. Mineral exploration and production facilities shall be to the maximum extent practicable designed, constructed and maintained in such a manner to maintain natural water flow regimes, avoid blocking surface drainage, and avoid erosion.

Guideline 10.5. Access routes to mineral exploration, production, and refining sites shall be designed and aligned so as to avoid adverse impacts on critical wildlife and vegetation areas to the maximum extent practicable.

Guideline 10.6. Drilling and production sites shall be prepared, constructed, and operated using the best practical techniques to prevent the release of pollutants or toxic substances into the environment.

Guideline 10.7. All drilling activities, supplies, and equipment shall be kept on barges, on drilling rigs, within ring levees, or on the well site.

Guideline 10.8. Drilling ring levees shall, to the maximum extent practicable, be replaced with smaller production levees or removed entirely.

Guideline 10.9. All drilling and production equipment, structures, and storage facilities shall be designed and constructed utilizing best practical techniques to withstand all expectable adverse conditions without releasing pollutants.

8.4 SPECIAL AQUATIC SITES

No special aquatic sites have been identified at this time.

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8.5 SUMMARY

Discharges associated with oil and gas exploration, development, and production in waters of the OCS of Louisiana will in general be consistent with relevant Lousiana Coastal Resources Program (LCRP) policies and guidelines. The consistency assessment is based on LCRP policies approved by local, state, and Federal governments. Relevant policies, with which the discharges will be consistent, are related to multiple uses of the coastal zone, management of all coastal habitats, management of specific habitat types (offshore areas, estuaries, wetlands and tideflats, and high energy coasts), and state water quality regulations. The consistency certification made by EPA will be submitted to the State of Louisiana for formal state review pursuant to 15 CFR 930.60-15 CFR 930.64.

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9. FEDERAL WATER QUALITY CRITERIA AND STATE WATER QUALITY STANDARDS

9.1 OVERVIEW

Compliance with Federal water quality criteria and State water quality standards at the edge of a 100-m mixing zone is assessed in this section using the waste stream characterizations provided in Section 3 and the modeling results presented in Section 4 of this document. The Federal marine water quality criteria for aquatic life (acute and chronic) and human health (for fish consumption) are presented in Table 9-1 for pollutants present in drilling fluids and produced water.

Discharges of drilling fluids and produced water covered by the OCS general permit will occur in Federal waters outside the boundaries of state waters. Issuance of the permit does not require compliance of State water quality standards. However, in order to account for discharges that may occur near the boundary of State waters, a comparison of projected pollutant concentrations at 100 m with state water quality standards is provided in this document.

9.2 FEDERAL WATER QUALITY CRITERIA

Using the number of dilutions and dispersions available for average case drilling fluid discharge scenarios (898 dilutions and 2,403 dispersions), a comparison of projected ambient pollutant concentrations at 100 m and water quality criteria is presented in Table 9-2. For organic pollutants, only the human health criterion for polyaromatic hydrocarbons (PAH) is exceeded (11-fold) by the ambient concentration projected by the modeling. The lowest effect levels for naphthalene (marine chronic) and PAH (marine acute) are also exceeded (8.6-fold and 1.1-fold, respectively).

For produced water, the average case discharge scenario used for comparisons at the edge of a 100 m mixing zone was based on the modeling results presented in Section 4 of this document (see Table 4-12) and the average case as documented in EPA (1985). This average case, based on an industry-wide 30-well survey, is characterized by an average discharge rate of 9,577. The number of dilutions used for estimation of pollutant concentrations is 238. The results of the comparison are presented in Table 9-3.

Table 9-1. Federal Water Quality Criteria[a]

Pollutant	Marine (Aquatic Life) Acute Criteria ($\mu g/\ell$)	Marine (Aquatic Life) Chronic Criteria ($\mu g/\ell$)	Human Health (Fish Consumption) Criteria ($\mu g/\ell$)
ORGANICS			
Acenaphthene	(970)[b]	(710)	
Benzene	(5,100)	(255)	40
Ethylbenzene	(430)	(21.5)	3,280
Naphthalene	(380)	(3.8)	27,000
Phenol	(5,800)	(290)	769,000
PAH	(300)	NA	31.1
Toluene	(3,700)	(3,200)	424,000
METALS			
Antimony	NA	NA	45,000
Arsenic	69	36	.0175
Beryllium	NA	NA	.117
Cadmium	43	9.3	NA
Chromium (Hex)	1,100	50	NA
Copper	2.9	2.9	NA
Lead	140	5.6	NA
Mercury	2.1	0.025	0.146
Nickel	75	8.3	100
Selenium	410	54	NA
Silver	2.3	NA	NA
Thallium	(2,130)	NA	48
Zinc	95	86	NA

[a] Source: U.S. EPA, 1989
[b] ( ) indicates a lowest observed effect level
[c] NA: Not Available

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Table 9-2. Comparison of Water Column Drilling Fluids Pollutant Concentrations to
Federal Water Quality Criteria

Pollutant	Ambient Concentration[a] (μg/ℓ)	Federal Water Quality Criteria Exceedances[b]		
		Marine Acute Criteria	Marine Chronic Criteria	Human Health Criteria
ORGANICS[c]				
Acenaphthene	1.51			
Benzene	0.490			
Ethylbenzene	5.87			
Naphthalene	32.5		(8.6x)[d]	
Phenol	0.117			
PAH	333	(1.1x)		11x
Toluene	3.65			
METALS[e]				
Antimony	0.854			
Arsenic	3.05			170x
Beryllium	7.68			66x
Cadmium	0.787			
Chromium	97.1		1.9x	
Copper	23.6	8.1x	8.1x	
Lead	13.3		2.4x	
Mercury	0.115		4.6x	
Nickel	2.74			
Selenium	0.129			
Silver	0.134			
Thallium	0.0745			
Zinc	48.5			

[a] Ambient concentrations are calculated as the effluent concentration + number of dilutions (organics) or dispersions (metals) available at 100 m.

[b] Source: U.S. EPA, 1989.

[c] The average number of dilutions used to calculate ambient concentrations at 100 m is 898.

[d] Parentheses indicate Federal criteria are expressed as a Lowest Effect Level (LOEL)

[e] The average number of dispersions used to calculated ambient concentrations at 100 m is 4,203.

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Table 9-3. Comparison of Water Column Produced Water Pollutant Concentrations to
Federal Water Quality Criteria

Pollutant	Ambient Concentration[a] (μg/ℓ)	Federal Water Quality Criteria Exceedances[b]		
		Marine Acute Criteria	Marine Chronic Criteria	Human Health Criteria
ORGANICS[c]				
Acenaphthene	0.008			
Benzene	62.2			1.5x
Ethylbenzene	0.412			
Naphthalene	1.96			
Pentachlorophenol	0.008			
Phenol	50.0			
PAH	2.03			
Toluene	4.50			
METALS				
Arsenic	0.433			25x
Cadmium	0.412			
Chromium	0.916			
Copper	0.101			
Lead	12.4		2.2x	
Mercury	0.015			
Nickel	0.580			
Selenium	1.02			
Silver	0.996			
Zinc	6.22			

[a] Ambient concentrations are calculated as the effluent concentration + number of dilutions at 100 m.
[b] Source: U.S. EPA, 1989.
[c] The average number of dilutions used to calculate ambient concentrations at 100 m is 238.
[d] Parentheses indicate Federal criteria are expressed as a Lowest Effect Level (LOEL)

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The projected concentrations of organic pollutants from produced water discharges exceed the human health criterion for benzene by 1.5-fold. The projected metal concentrations exceed the human health criterion for arsenic (25-fold) and the marine chronic criterion for lead (2-fold).

9.3   LOUISIANA STATE WATER QUALITY STANDARDS

The Louisiana Water Quality Regulations, set forth by the Louisiana Department of Environmental Quality in Title 33, Part IX, establish water quality standards and effluent standards for discharges to state waters. In the general water quality criteria, the state of Louisiana has established that "Toxic Substances shall not be present in quantities that alone or in combination will be toxic to plant or animal life." General criteria apply at all times to the surface waters of the state, including waters within a mixing zone, except where specifically exempted. The following general criteria are applicable to the discharges covered by the OCS general permit:

- Aesthetics,
- Color,
- Floating, Suspended, and Settleable Solids,
- Taste and Odor,
- Toxic Substances,
- Oil and Grease,
- Foaming and Frothing Materials, and
- Turbidity.

The standard for solids requires that "there shall be no substances present in concentrations sufficient to produce distinctly visible solids or scum, nor shall there be any information of long term bottom deposits of slimes or sludge banks attributable to waste discharges from municipal, industrial, or other sources including agricultural practices, mining, dredging and the exploration for and the production of oil and natural gas." The toxicity standard requires that concentrations shall not exceed 0.01 x 96-hour LC50 for persistent toxicants and 0.1 x LC50 for non-persistent toxicants. The standard for turbidity states that discharges ". . . shall not cause substantial visual contrast with the natural appearances of the waters of the state" (in this case, not exceed background values plus 10%).

Numerical standards must be met outside a 100-m mixing zone for Gulf waters of the State of Louisiana and are established for the following parameters:

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- pH - 6.0 to 9.0

- chlorides, sulfates, and total dissolved solids - determined for specific stream segments

- dissolved oxygen - not less than 5 mg/l

- temperature - maximum 2.2°C above ambient October to May;
  maximum 0.83°C above ambient June to September;
  maximum temperature 35°C

- bacteria - <14 per dl (MPN); <43 per dl (MPN) for 90% of samples

- toxic substances:

Phenols	-	440 μg/l
DDT	-	0.13 μg/l (not to be exceeded, NTE); 0.001 μg/l (24-hr average)
TDE (DDD)	-	3.6 μg/l (NTE)
DDE	-	14 μg/l (NTE)
Endrin	-	0.037 μg/l (NTE); 0.0023 μg (24-hr average)
PCBs	-	10.0 μg/l (NTE); 0.030 μg/l (24-hr average)
Toxaphene	-	0.070 μg/l (NTE)
Dieldrin	-	0.071 μg/l (NTE); 0.0019 μg/l (24-hr average)
Aldrin	-	1.3 μg/l (NTE)
Chlordane	-	0.09 μg/l (NTE); 0.0040 μg/l (24-hr average)

Under Louisiana's water quality standards, mixing zones are portions of water bodies that are exempted from criteria for those substances rendered nontoxic by dilution, dissipation, or transformation. Mixing zones must be defined and have identifiable limits and they shall not overlap. Mixing must be accomplished as quickly as possible to insure that the waste is mixed with the allocated dilution water in the smallest practicable area. Mixing zones must be free from floating debris, oil, and materials in concentration to cause acute toxicity.

The Water Quality Regulations also include effluent standards for discharges from oil and gas exploration and production activities. For state waters in the Gulf of Mexico the standards require no discharges of muds and cuttings or produced water within 1,300 feet of an active oyster lease, live natural oyster or other molluscan reef, designated oyster seed bed, or sea grass bed. No discharge of drilling fluids shall be made in such a manner as to allow deposition of drill cuttings or drilling fluids in or upon any active oyster lease. No produced water shall be discharged in a manner that, at any time, facilitates the incorporation of significant quantities of hydrocarbons or radionuclides into sediment or biota.

The general and numeric standards of Louisiana's Water Quality Regulations will not be exceeded by discharges from oil and gas facilities covered by the OCS general permit when in compliance with the conditions and limitations set forth by that permit.

9.4 TEXAS WATER QUALITY STANDARDS

The Texas Water Quality Standards, set forth by the Texas Water Commission, establish general and numerical criteria for discharges to state waters. The Commission delegates the responsibility of controlling pollution to state waters from activities associated with the exploration, development, and production of oil and gas or geothermal resources to the Railroad Commission of Texas. All authorized discharges, however, must meet the standards as set forth by the Texas Water Commission.

General criteria apply at all times to all surface waters of the state (i.e., including waters within a mixing zone), except where specifically exempted, and apply to the following parameters:

- Aesthetics,
- Color,
- Floating, Suspended, and Settleable Solids,
- Taste and Odor,
- Toxic Substances,
- Oil and Grease,
- Foaming or Frothing Materials, and
- Turbidity.

Texas Railroad Commission Rule 8 of the Statewide Rule for Oil, Gas, and Geothermal Operations sets specific criteria for oil and gas operations. These general criteria require that all discharges meet the free oil limitations of no visual sheen and that adequate measures are taken to prevent pollutants from escaping to the surrounding waters (Statewide Rule for Oil, Gas and Geothermal Operations, §3.8 Rule 9(e)).

General criteria clearly appropriate for regulating drilling fluids and cuttings discharges include those for floating, suspended and settleable solids, toxic substances, and turbidity. The standards for solids requires that "surface water be essentially free of floating debris and suspended solids that are conducive to producing adverse responses in aquatic organisms or putrescible sludge deposits or sediment layers which adversely affect benthic biota or any lawful uses"; "surface waters be essentially free of settleable solids conductive to changes in flow characteristics . . . or untimely filling. . . "; and "waste discharges shall not cause substantial and persistent changes from ambient conditions of turbidity or color."

Numerical criteria for water of the State of Texas, which are standards that must be met outside the mixing zone, are established for the following parameters;

- pH - 6.5 to 9.0

- chlorides, sulfates, and total dissolved solids - determined for specific stream segments

- dissolved oxygen - not less than 5 mg/l

- temperature -   maximum differential Fall, Winter, Spring 4°F;
                  maximum differential June - August 1.5°F;
                  maximum temperature 95°F

- bacteria - <14 per dl (MPN); <43 per dl (MPN) for 90% of samples

- toxic substances:

    - nonpersistent toxic materials shall not exceed 0.1 of the 96-hour LC50
    - persistent toxic materials shall not exceed 0.05 of the 96-hour LC50
    - bioaccumulative toxic materials shall not exceed 0.01 of the 96-hour LC50.

In the Texas standards, specific numerical criteria are established for toxic substances for which the state has determined that adequate toxicity information is available (31 TAC 307.6(c)). The numerical criteria are to be met at the edge of the mixing zone with the exception of acute criteria which must be achieved within a smaller zone of initial dilution. Mixing zones are individually specified for industrial discharges. In addition, the Texas Water Commission, as part of the implementation policy of their water quality standards, has established maximum allowable concentrations for each of the hazardous metals that can be discharged to coastal or inland waters (Hazardous Metal Rule (31 TAC 319). These are end of pipe limitations. The state marine acute, marine chronic, and hazardous metals criteria are listed in Table 9-4 for metals present in drilling fluids and produced water.

The general criteria of the Texas Water Quality Standards will not be exceeded by discharges from facilities covered by the OCS general permit when in compliance with the permits conditions and limitations. A comparison of projected ambient concentrations of pollutants from discharges of drilling fluids and produced water at the edge of a 100-m mixing zone are compared to the Texas numeric limitations in Tables 9-5 and 9-6, respectively. For drilling fluid discharges, the marine acute criterion for copper is exceeded by 5-fold at 100 m. The marine chronic criteria for chromium (2-fold), copper (5-fold), lead (2-fold), and mercury (5-fold) also are exceeded. For produced water, only the marine chronic criterion for lead is exceeded (2-fold).

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Table 9-4. Texas Water Quality Criteria for Metals

	Marine Acute Criteria ($\mu g/l$)	Marine Chronic Criteria ($\mu g/l$)	Hazardous Metals Criteria ($\mu g/l$)
Arsenic	149	78	100
Barium	-	-	1,000
Cadmium	45.62	10.02	100
Chromium (6+)	1,100	50	500 (Tot)
Copper	4.37	4.37	500
Lead	140	5.6	500
Mercury	2.1	0.025	5
Nickel	119	13.2	1,000
Selenium	410	54	100
Silver	2.3	-	50
Zinc	98	89	1,000

Table 9-5. Comparison of Water Column Drilling Fluids Pollutant Concentrations to
Texas Water Quality Criteria

| Pollutant | Ambient Concentration[a] (μg/ℓ) | Texas Water Quality Criteria Exceedances[b] | | |
		Marine Acute Criteria	Marine Chronic Criteria	Hazardous Metals Criteria
METALS				
Arsenic	3.05			
Cadmium	0.787			
Chromium	97.1		1.9x	
Copper	23.6	5.4x	5.4x	
Lead	13.3		2.4x	
Mercury	0.115		4.6x	
Nickel	2.74			
Selenium	0.129			
Silver	0.134			
Zinc	48.5			

[a] Ambient metals concentrations are calculated as the effluent concentration ÷ number of dispersions available at 100 m.

Table 9-6. Comparison of Water Column Produced Water Pollutant Concentrations to
Texas Water Quality Criteria

Pollutant	Ambient Concentration[a] ($\mu g/\ell$)	Texas Water Quality Criteria Exceedances[b]		
		Marine Acute Criteria	Marine Chronic Criteria	Hazardous Metals Criteria
METALS				
Arsenic	0.433			
Cadmium	0.412			
Chromium	0.916			
Copper	0.101			
Lead	12.4		2.2x	
Mercury	0.015			
Nickel	0.580			
Selenium	1.02			
Silver	0.996			
Zinc	6.22			

[a] Ambient metals concentrations are calculated as the effluent concentration ÷ number of dispersions available at 100 m.

10. POTENTIAL IMPACTS

10.1 OVERVIEW

Discharges, particularly drilling fluids, cuttings, and produced water, may adversely affect the marine environment in which they are released. This statement is based on an extensive database of single species toxicity tests and field observations discussed in Section 5 of this report. If an adverse impact occurs, the severity of the impact depends upon several factors including: toxicity of the discharge to endemic biota, the exposure concentration over time, the capacity of the biota to accumulate components of the discharge (bioaccumulation) and chemical/physical properties of the discharge and receiving waters. Those factors and others form the basis for a risk assessment whereby toxicity and exposure concentrations are used to estimate potential impacts. Unfortunately, much more data is available on toxicity than exposure concerning the effects of drilling fluids, cuttings, and produced water and there is a paucity of data on most other factors. A brief discussion of potential impacts based on current information follows. Special emphasis is placed on benthic communities because they appear to be most susceptible to these discharges and to fisheries because of their commercial importance.

10.2 TOXICITY

10.2.1 Potential Impacts from Toxicity of Drilling Fluids and Cuttings

Of the major ingredients of water-based drilling fluids, only chrome or ferrochrome lignosulfonate and sodium hydroxide are considered even moderately toxic to marine organisms (Neff, 1985; NRC, 1983). Most of the metals found in used drilling fluids appear in forms which have low toxicities or limited bioavailability to marine organisms (Neff et al., 1978; Hunt and Smith, 1983; Luoma, 1983). Although most major ingredients of drilling fluids apparently have low toxicities to marine organisms, some of the specialty additives that are frequently used to solve specific problems are toxic. The most toxic of these additives are diesel fuel, chromate salts, surfactants, paraformaldehyde, and other biocides (NRC, 1983; Conklin et al., 1983).

In acute bioassay tests for drilling fluids, the most sensitive of the species tested include dock shrimp, lobster larvae, juvenile ocean scallops, and pink salmon fry (NRC, 1983; Neff, 1985). In most cases,

the larvae and/or juvenile life stages are more sensitive than adult stages. Larval, juvenile, and molting crustaceans appear to be more sensitive to drilling fluids than are other life stages and species. The toxicity of drilling fluids seems to be due to a combination of the chemical toxicity of the water-accommodated mud ingredients, the physical irritations caused by chemicals associated with the particulate phase, and damage to delicate gill and other body structures from the mud particles (Neff, 1985). Heavily treated drilling fluids are the most toxic.

Numerous chronic responses of finfish and shellfish species to drilling fluids have been observed in laboratory studies (Table 10-1). In finfish, chronic responses include decreased development rate, depressed embryonic heart beat, development abnormalities, gill histopathology, feeding and avoidance behavior, and effects on growth (Houghton et al., 1980; Crawford and Gates, 1981; Olla et al., 1982; Sharp et al., 1984). In crustaceans, sublethal responses included reduced chemosensory responses, inhibition of feeding, altered behavior in larvae and juveniles, cessation of swimming in larvae, extended duration of larvae and juvenile development, decrease or increase in enzyme activity, gill histopathology, and reduced long-term larval and juvenile survival (Atema et al., 1982; Bookhout et al., 1984; Capuzzo and Derby, 1982; Carls and Rice, 1980; Carr et al., 1980; Conklin et al., 1980; Gerber et al., 1980, 1981; Gilbert, 1981; Houghton et al., 1980; Neff, 1980; Olla et al., 1982). Sublethal responses in bivalve mollusks included depressed filtration, byssus thread formation, NH_3 excretion, shell growth, condition index, increased respiration, altered free amino acid ratios, and altered behavior (Gerber et al., 1980, 1981; Gilbert, 1981, 1982; Houghton et al., 1980; Neff, 1980; Powell et al., 1982; Rubinstein et al., 1980; Olla et al., 1982). Several of the drilling fluids tested in these studies contained diesel fuel that could have contributed significantly to their toxicity.

The components of drilling fluids of major environmental concern to investigators are petroleum hydrocarbons and heavy metals. The major concern is whether they can accumulate in tissues to concentrations high enough to be toxic to the animals themselves and/or to higher trophic levels (Neff, 1985). The majority of petroleum hydrocarbons in water-based drilling fluids containing diesel oil will be adsorbed to the clay fraction of the drilling fluid and will be dispersed in the water column with the slow-settling fraction (Breteler et al., 1983). Most of the hydrocarbons may eventually desorb from the clay and evaporate to the atmosphere, be degraded by bacteria, or be deposited with the clay on the bottom (Neff, 1985). Although the bioavailability of petroleum hydrocarbons in drilling fluids has not been investigated, hydrocarbons in solution are generally much more bioavailable to marine organisms than those which are absorbed in bottom sediments (Rossi, 1977; Roesijadi et al., 1978; McCain et al., 1978; Lyes, 1979; Neff, 1979, 1982; Augenfield et al., 1982; Anderson, 1982). Elevated levels of heavy metals discharged with drilling fluids have been reported in the water column, bottom sediments, or both in the vicinity of offshore exploratory wells (Crippen et al., 1980; Ecomar, 1978; EG&G, 1982; Gettleson and Laird, 1980; Meek and

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Table 10-1. Summary of Chronic and/or Sublethal Responses of Marine Animals to Water-based Chrome or Ferrochrome Lignosulfonate-type Drilling Fluids

Animals	Nature and Length of Exposure[a]	Responses	References
Bivalve Molluscs (Six species)	50-33,000 ppm suspension for 3-100	Depressed filtration, byssus thread formation, NH_3 excretion, shell growth, condition index, increased respiration, altered free amino acid ratios, behavior	Gerber et al., 1980, 1981; Gilbert, 1981, 1982; Houghton et al., 1980; Neff, 1980; Powell et al., 1982; Rubinstein et al., 1980; Olla et al., 1982
Crustaceans (Fifteen species)	7.7-100,000 ppm suspension for 5 min - 42 days; 1-7 mm layer for up to 4 days	Decreased chemosensory response, inhibition of feeding, altered behavior in larvae and juveniles, cessation of swimming in larvae, increased duration of larval and juvenile development, decreased or increased enzyme activity, gill histopathology, decreased long-term larval and juvenile survival	Atema et al., 1982b; Bookhout et al., 1984; Capuzzo and Derby, 1982; Carls and Rice, 1980; Carr et al., 1980; Conklin et al., 1980; Gerber et al., 1980, 1981; Gilbert, 1981; Houghton et al., 1980; Neff, 1980; Olla et al., 1982
Polychaete Worms (One species)	10 ppm suspension, 100 days	33% mortality	Rubinstein et al., 1980
Echinoderms (Five species)	10-100,000 ppm suspensions 2 days - duration of larval development	Depressed fertilization, decreased development rate, increased incidence of development anomalies	Chaffee and Spies, 1982; Crawford, 1983; Crawford and Gates, 1981.

Source: Neff, 1985

[a] The lowest exposure concentrations eliciting a response are given.

Ray, 1980; Tillery and Thomas, 1980; Wheeler et al., 1980; Trocine et al., 1981). As with petroleum hydrocarbons, the bioavailability of sediment-absorbed metals is generally low (Jenne and Luoma, 1977; Bryan, 1983; Luoma, 1983).

Critical determinants of the impacts of discharged drilling fluids and cuttings on water column biota are the rate and extent of the dispersion and dilution processes. The effects of a material like drilling fluid on water column organisms will depend not only on its inherent toxicity, but also on actual exposure concentrations and durations. Offshore field studies have shown that drilling fluids discharged to the oceans generally are diluted to low concentrations before they can produce adverse effects in water column organisms (Ayers et al., 1980a, 1980b; Ecomar, 1978, 1983; Houghton et al., 1980; Northern Technical Services, 1983). Many questions remain, however, regarding the dispersion and effects of drilling discharges in enclosed, low-energy environments and shallow-water environments, such as bays and estuaries.

Field investigations have shown that, in all but deep or high-energy environments, drilling fluids and cuttings initially will settle very rapidly from the discharge plume to the bottom. The severity of impact of deposition on the benthos is directly related to the amount of material accumulating on the substrate, which in turn is related to the amount and physical characteristics of the material discharged, and to the environmental conditions, such as current speed and water depth, at the time and site of discharge (Neff, 1985). In high energy environments, less drilling fluids or cuttings accumulate, and the impact on benthos would be minimal and of short duration. In low energy and depositional environments, more material accumulates, and there may be a reduction in the abundance of some benthic species (Neff, 1985). In contrast, factors enhancing local dispersion contribute to regional-scale, low-level contamination. Such types of pollutant effects, if they occur, have historically been very difficult to identify and ascribe cause and effect relationships.

10.2.2 Potential Impact from Toxicity of Produced Water

The chemical properties of produced water that could cause harmful effects in marine organisms and ecosystems include elevated salinity, altered ion ratios, low dissolved oxygen, heavy metals, petroleum hydrocarbons and other organics (Neff, 1985). In addition, deck drainage may contain a variety of chemicals such as detergents, solvents, and metals. Chemicals such as biocides, coagulants, corrosion inhibitors, cleaners, dispersants also may appear in the effluent waters (Middleditch, 1984; Neff, 1985). The major constituents of concern in produced water are petroleum hydrocarbons and heavy metals (Neff, 1985). Other produced water constituents or properties have either been shown to be unlikely contributors to significant

impacts in the marine environment (elevated salinity and altered ion ratios) or their impacts have not been quantified (e.g., BOD; Neff, 1985).

In contrast to drilling fluids, relatively little information is available concerning the acute lethal toxicity of produced water to marine organisms. The majority of bioassays that have been conducted with produced water indicate that most are not very toxic to finfish and shellfish (Rose and Ward, 1981; Andreasen and Spears, 1983; Zein-Eldin and Keney, 1978; Palmer, 1978; U.S. DOI, 1975). The most toxic produced waters tested were those that had been treated with biocides. The most sensitive organisms evaluated were larval brown shrimp (Rose and Ward, 1981) and pink salmon fry (Thomas and Rice, 1979).

Even less information is available concerning the chronic and/or sublethal effects of produced water on marine organisms. Most of these effects have been inferred from published information about the chronic and sublethal effects of petroleum hydrocarbons and heavy metals to marine organisms (Koons et al., 1977; Menzie, 1982; Middleditch, 1984). The few chronic and sublethal effect studies performed indicate, generally, produced water has a fairly low toxicity (on the order of 1-10% for 96-hour LC50s).

As in the case with drilling fluids, petroleum hydrocarbons in discharged produced water may evaporate or adsorb to suspended particles and be deposited in bottom sediments. Studies conducted in Trinity Bay, Texas, a shallow-water, low-energy environment, indicated that higher molecular weight hydrocarbons accumulated in bottom sediments near the discharge site, while light aliphatic and aromatic hydrocarbons from produced water were not found elevated to the same degree (Armstrong et al., 1979).

Although there have been several laboratory investigations of bioaccumulation of metals from drilling fluids, there have been no published reports to date of laboratory studies of the bioaccumulation of metals from produced water by marine organisms (Neff, 1985). Of particular concern are the radionuclides ^{228}Ra and ^{228}Ra, which naturally occur in sea water and which readily bioaccumulate in the calcified exoskeleton of marine invertebrates and bones of fishes (van der Borght, 1963; Holtzman, 1969; Moore et al., 1973).

Several field studies of coastal and nearshore sites have been conducted to assess short- and long-term, near-field and area-wide impacts caused by produced water discharges (Neff, 1985; Boesch and Rabalais, 1989; Armstrong et al., 1979). These studies have demonstrated an accumulation of petroleum hydrocarbons from produced water in surficial sediments to about 1,000 meters from the point of discharge in shallow turbid waters (Armstrong et al., 1979). In greater water depths and lower suspended sediment

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concentrations, a much smaller fraction of hydrocarbons in produced water discharges is deposited in bottom sediments (Middleditch, 1981).

In offshore areas, produced water is apparently diluted very rapidly following discharge. Significant elevations in salinity, elevated concentrations of hydrocarbons or metals, or decreased dissolved oxygen are not usually observed at distances greater than 100 or 200 meters from the point of discharge (Neff, 1985). Because of the apparent degree of mixing with sea water, most physical/chemical features of produced water do not appear to pose a hazard to water column biota in open waters. Effects on the benthos in these areas are expected to be localized or of a relatively small magnitude.

The environmental fate of produced water in shallow waters (<20 m), however, is a concern. If suspended sediment concentrations are high, dissolved and colloidal hydrocarbons and metals from produced water will become adsorbed to suspended particles and impact bottom sediments. If the volume and turnover rate of receiving waters is very small, mixing and dilution of discharged produced water will not be as rapid as in offshore areas and potential water column impacts may occur.

10.3 POTENTIAL IMPACT OF DISCHARGES ON BENTHOS

The effects of drilling and production discharges on benthos result from that portion of the material that settles to the bottom where it can be incorporated into the sediments, resuspended, transported, and dispersed (NRC, 1983). For drilling fluids, the concentration of solids in bottom sediments depends on the types and quantities of drilling fluids discharged, hydrographic conditions at the time of discharge, and the height above the bottom at which the discharge is made (Gettleson and Laird, 1980). In high energy environments, little drilling fluid and cuttings accumulate and impacts on the benthos are minimal and of short duration. In low energy environments, more material accumulates, and there can be localized impacts on benthic organisms. In the case of produced water, in shallow water environments where suspended sediment concentrations are high, dissolved and colloidal hydrocarbons and metals from produced water tend to become adsorbed to suspended particles and settle to the bottom (Armstrong, 1981). In deeper waters, elevated levels of hydrocarbons are restricted to a much smaller area of the bottom or are not detected at all (Middleditch, 1981).

10.3.1 Drilling Fluids

The major ingredients of water-based drilling fluids, bentonite clay and barite, are practically inert toxicologically, although they may cause physical damage to marine organisms through abrasion or clogging.

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Several studies have been conducted investigating the sublethal responses of benthic fauna to drilling fluids. Responses observed include altered burrowing behavior; chemosensory responses; alterations in embryological or larval development; depressed feeding; decreased food assimilation and growth efficiency; altered respiration and nitrogen excretion rates; and others (see Table 10-1).

In the low-energy environment of coastal bays and estuaries, more drilling fluids and cuttings will accumulate on the bottom sediments, and there will be an increase in the reductions in the abundance of some benthic species due to burial, incompatibility with clay-sized particles, or chemical toxicity of drilling fluid or cuttings components (Neff, 1985).

In offshore areas, the impacts of drilling fluids and cuttings discharges may be very localized or patchy in distribution, and may be difficult to distinguish from the effects of other local changes due to drilling activities. These activities include the rain of organic material from the fouling community on the rig and increased predator pressure due to the reef effect or sea bed scour around drilling structures.

Most offshore field studies have shown a minimal impact of water-based drilling fluid discharges on the benthos except immediately adjacent to platforms where a cuttings pile was formed and persisted. Some changes in the local infaunal community structure will occur due to burial and the altered sediment character. The increased bottom microrelief afforded by the accumulation of cuttings may also attract fish and other motile animals and alter the character of epibentic infaunal communities (Neff, 1985). However, when oil-based drilling fluids are used and large amounts of oil contaminated cuttings are discharged, severe adverse impacts on the benthos may extend out as much as 200 meters from the platform and the benthic community may be altered out as much as 2,000 meters from the platform (Davies et al., 1983). In the low-energy environment of coastal bays and estuaries, more drilling fluids and cuttings will accumulate on the bottom sediments, and there will be an increase in the reductions in abundance of some benthic species due to burial, incompatibility with clay-sized particles, or chemical toxicity of drilling fluid or cuttings components (Neff, 1985).

10.3.2 Produced Water

The benthic community is most likely to be significantly impacted by produced water discharges, especially if the produced water is hypersaline. Organic and metallic pollutants in produced water ultimately affect the benthos even if the plume does not impact the bottom directly, because these chemical constituents would be expected to quickly absorb to suspend matter in the water column and eventually settle to the bottom (Armstrong et al., 1979).

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In areas where a hypersaline produced water plume contacts the bottom, mortality can be expected to occur as a result of anoxic and hypersaline conditions. The extent of these effects will depend on the duration, volume, and dispersion of the plume. It is likely that the benthic community, especially infauna and less mobile epifauna, would be severely disrupted in the immediate vicinity of the discharge. Armstrong et al. (1979) noted severe disruption of benthos within 150 m (490 ft) of the discharge point in Trinity Bay, Texas.

Farther from the discharge site, chronic effects may occur and are likely to impact benthos over a large area. Chronic effects may occur primarily from exposure to dissolved or deposited metals and hydrocarbons. In other areas it has been noted that compounds at very low concentration in produced water, especially substituted naphthalenes, can accumulate to high concentrations in sediments and in biota (Armstrong et al., 1979). This occurs even in areas where the discharge plume dilutes rapidly (Armstrong et al., 1979).

Hydrocarbons are known to adsorb to sediment and many often remain for years (Platt and Mackie, 1980). Armstrong et al. (1979) noted definite correlations in Trinity Bay, Texas between sediment naphthalene concentrations from brine effluent in the vicinity of an oil separator platform and the number of benthic species and individuals. Effluent production ranged from 4,100-10,000 bbl/day, with an average salinity of 64 ppt and average oil concentrations of 15 ppm (1.62 ppm naphthalenes). The sediment was nearly devoid of organisms within 15 m (49 ft.) of the outfall, with "severely depressed benthic fauna" to 150 m (460 ft) of the outfall. A "low, possibility 2 ppm, persistent concentration of naphthalenes" was considered capable of restricting many species (Armstrong et al., 1979). The use of a number of outfalls was also noted to be more harmful than a single outfall. Location of the outfall only 1 m from the bottom, however, makes extrapolation of this study to other areas questionable.

Neff et al. (1988) report little chemical contamination at their study sites that exceeded a 300 m radius. However, in Boesch and Rabalais (1989), hydrocarbon contamination at one study site (total alkanes, FFPI) at 800 m was about three times higher than at 1300 m; at another site, contamination (FFPI) at 600 m was 3.5-times that observed at 2,800 m. Thus, background was achieved at these sites somewhere between 600 m and 2,800 m or between 800 m and 1,300 m. Also at one of these sites, resolved saturates in one set of stations 1,100 m from the discharge were 16-fold those at 1,500 m and in another set of stations were 15-fold higher at 1,900 m than at 2,800 m. At these same sets of stations, total PAHs were 2.4-fold higher at 1,100 m than at 1,500 m and >4.5-fold higher at 1,900 m than at 2,800 m. These data suggest background levels may have been achieved at a distance anywhere between 600 m and 2,800 m.

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It is impossible to predict the extent to which benthos may be affected for any given volume of produced water discharged, due to uncertainties of well locations, variations in chemical composition of produced water, and plume characteristics. Acute toxic effects are more likely when the effluent plume is hypersaline and resists dilution and dispersion, but bioaccumulation and toxicity can occur even when dilution is great (Armstrong et al., 1979). In Trinity Bay, Texas, the accumulation of hydrocarbons and the disruption of benthic populations occurred rapidly and persisted for as much as 6 months (Armstrong et al., 1979).

10.4   POTENTIAL FOR BIOACCUMULATION

Ingestion of oil will vary widely between species. The species that feed in benthic environments by routing in silt or mud to expose prey may ingest larger amounts of hydrocarbons because a wide variety of petroleum components settle and aggregate in benthic environments (NAS, 1975). Contamination of organisms and sediments may be additive over a long period of time. The presence of hydrocarbons in benthic organisms has been related to the presence of such hydrocarbons in nearby sediments (NAS, 1975). Sperm whales, pygmy sperm whales, and Risso's dolphins feed on benthic organisms, and therefore may be particularly vulnerable to ingestion of oil while feeding.

Most odontocetes (toothed whales) feed on fish, molluscs, and crustaceans in the water column. The ingestion of petroleum components by most toothed whales is not likely, except in play activities and as contamination in food. Dolphins that feed on fish concentrated near oil and gas structures, and on offal from shrimp trawls near OCS structures, are most likely to ingest fish with elevated hydrocarbon concentrations. Such fish may have higher parasite loads, bacterial infections, and other maladies associated with hydrocarbon pollution, but such factors may not affect marine mammals except under extreme conditions.

Ingestion of petroleum suspended in the water column and floating on the surface is most probable for the Mysticetes (baleen whales). The large quantities of water that are filtered by theses large whales during feeding may contain petroleum. It is doubtful that sufficient petroleum would be ingested to cause death, but fouling of baleen plates, irritations of buccal membranes, and disruption of absorption of nutrients is likely.

Most other constituents of drilling fluids have been found to have low toxicities to marine organisms. However, diesel fuel may contribute significantly to the toxicity of those drilling fluids that contain it (Neff, 1985). Because of the low bioavailability of sediment-absorbed hydrocarbons, most benthic animals can tolerate relatively high concentrations of sediment hydrocarbons, which in this case result from the addition

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of diesel fuel to drilling muds. Some impacts on the benthos could occur, however, if large amounts of hydrocarbon-laden drilling fluid solids accumulate in a particular area (Neff, 1985). When oil-based drilling fluids are used and large amounts of oil contaminated cuttings are discharged, several adverse impacts on the benthos may extend out as much as 200 meters from the platform and the benthic community may be altered out as much as 2,000 meters from the platform (Davies et al., 1983). There is evidence to indicate that heavy metals are accumulated in the marine food web in a variety of organisms at various trophic levels and through a variety of paths of uptake. Most of the characteristics of heavy metals favor magnification in the food web. Therefore, marine mammals might ingest heavy metals that could result in an accumulation of these substances in the lipids of those animals.

10.5   POTENTIAL IMPACT OF DISCHARGES ON FISHERIES

Although several types of discharges will take place during oil and gas exploratory, development, and production activities in the territorial seas of Texas and Louisiana, only those discharges which would occur in sufficient volume to elicit a potential impact on finfish and shellfish populations, and thus the fisheries, are discussed here. These discharges are drilling fluids, cuttings, and produced water. Other discharges (sanitary waste, deck drainage, completion fluids, etc.) may have associated toxic effects, but the volume of discharges from these sources are relatively small in comparison. Further consideration may need to be given to these discharges in shallow or low energy areas or where there is a high concentration of facilities. However, in the case of a single facility, any potential effects could be so localized as to have no significant impact on entire fish populations.

10.6   SOCIOECONOMIC CONSEQUENCES OF DISCHARGES ON FISHERIES

The importance of the commercial and recreational fisheries to the regional economy of the Gulf of Mexico and to the state economies of Texas and Louisiana was discussed in Section 7. This section focuses on assessing the socioeconomic consequences of adverse effects on these fisheries from discharges of drilling muds, cuttings, and produced waters.

As previously discussed, the Gulf of Mexico led all other regions of the country during 1985 and 1986 in pounds of commercial fish landed and was second to the Pacific and Alaska region in the value of the catch landed. Louisiana ranked first among the states in 1986 commercial landings and second in value. Although Texas ranked eleventh among all states in landings, it ranked third in value (NMFS, 1987). The Gulf shrimp fishery represents the single most valuable fishery in landings, and the menhaden purse seine

fishery is the most important fishery in pounds landed. In 1985, Texas ranked second among the Gulf states in the total number of fish caught by recreational fishermen, whereas Louisiana ranked third.

In 1985, there were 948 processing and wholesale plants in the Gulf area that employed over 15,000 people (NMFS, 1987). Louisiana had 278 processing and wholesale plants (29% of the total) that employed over 4,000 people, while Texas had 164 plants (17% of the total) that employed over 2,600 people (NMFS, 1987).

Results from the National Marine Fisheries Service's statistical survey indicate that in the Gulf region, recreational fishermen made over 18 million fishing trips during 1986 (NMFS, 1987). The fishing trips included trips to the shore and trips by party/charter boats or by private/rental boats. Recreational activities such as crabbing, oystering, and trout fishing that occur in the coastal beaches, barrier islands, estuarine bays and sounds, river deltas, and tidal marshes of Texas and Louisiana grow every year in participation and economic significance.

Oil and gas structures are a major focus of all forms of offshore recreational fishing and some types of commercial fishing (MMS, 1982b; 1983b; 1984). Platforms receive the most attention by sport fishermen in the Texas and Louisiana territorial seas. Studies by Ditton and Graefe (1978) and Dugas et al. (1979) show that the preferred fishing locations for private and charterboat fishermen in portions of the western and central Gulf are oil and gas structures. Although any one structure or structure complex may be a popular fishing destination, the ones located in nearshore areas in close association with major coastal population access points are visited most often. Ditton and Graefe (1978) reported that 23% of party charter operations taken in the Freeport-Galveston area and 50% of resident operations in the Houston-Galveston area were taken to platform structures.

If significant discharges were to occur, fish eggs, larvae, and juveniles could be damaged or destroyed, and fishing (such as reef fishing or shrimping) could be disrupted in fishing areas within close proximity to the platform discharge. Discharges may create turbidity plumes several hundred to several thousand yards in length, but would affect only those waters in the vicinity of discharging rigs. Part of the area around the drilling activity would be buried by drilling muds and cuttings, impacting sessile organisms such as oyster and coral reefs, and thus the fishing activities associated with them. However, recovery is generally rapid, depending on depth of burial, grain size of discharged materials, and local bottom currents.

Many of the fish species that congregate around petroleum structures are prime sport-fishing targets (snapper, mackerels, etc). Concerns regarding sublethal effects of discharges on major sport-fishing targets

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around platforms have been addressed by the National Academy of Sciences (1975), Gallaway (1980), and the Norwegian government (Jensen et al., 1984). They concluded that trace contaminants were noted in some sport fish collected near platforms; however, these contaminants were not significant and there was little evidence of bioaccumulation.

Any impacts on fisheries around offshore platforms on the OCS are expected to be relatively localized and short-term, because discharges would be into a large body of water in which dilution and dispersion are rapid. An exception could occur from the indirect effect on commercial and recreational fishing resulting from a high regional impact affecting biological productivity.

10.7   SUMMARY AND CONCLUSIONS

Discharges of drilling muds, cuttings, and produced waters apparently cause localized impacts on marine organisms in offshore areas and are not likely to impact populations or the fisheries' harvests dependent on sustained populations. This is due to the dispersion and dilution of discharges in the open ocean.

The Region has determined that the available information is sufficient to determine that routine discharges from oil and gas exploration, development, and production activities in the Gulf of Mexico OCS, in compliance with permit limitations and conditions, will not cause unreasonable degradation of the marine environment. The permit conditions that require data collection and reporting will be used to assess those potential impacts for which more data are desired to validate the Region's determination.

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